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Pacific Marine Science Report 80-1

OBSERVATIONS OF SEAWATER TEMPERATURE AND SALINITY AT BRITISH COLUMBIA SHORE STATIONS 1977

by

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Abstract

Surface (approx. 1-metre-depth) oceanic salinities and temperatures have been recorded once a day at several locations on the coast of British Columbia for varying lengths of time - from a few months to a few decades. This publication presents the data obtained in 1977 from sixteen such shore stations. Fourteen of the sites are Ministry of Transport (MOT) lightstations; the remaining two are the Pacific Biological Station at Departure Bay and the meteorological station at Cape St. James.

Temperatures are determined at all sixteen sites by means of mercury-in-glass thermometers. Salinities are obtained at fourteen sites only; they are determined at thirteen by hydrometer and at the remaining one by laboratory-model inductive (electrodeless) salinometer.

The data obtained are presented in two forms. Firstly, tables provide, for each site, the monthly means and the associated standard deviations, as well as the maximum and minimum values recorded during each month; the annual means are also listed. Secondly, graphs indicate the behaviour, throughout the year, of the data after the higher-frequency oscillations (e.g., those of tidal period) have been removed ("smoothed") by the use of a seven-day normally-weighted running mean.

Introduction

A program involving once-daily observations of sea-surface salinities and/or temperatures at numerous locations on the coast of British Columbia has been in effect since the early 1930's. Most of these sampling sites have been at lightstations maintained by the Ministry of Transport (MOT). The number of sites reporting at any given time has varied throughout the course of the program; sampling has been discontinued (and in a few cases later resumed) at some places and commenced (not necessarily simultaneously) at others.

The data previously obtained have been published either in reports of the present series or in those of its organizational predecessors. For details regarding the sampling stations and the publications involved prior to 1972, the reader is referred to the review by Hollister and Sandnes (1972).

From 1972 through 1977, data were made available from sixteen shore stations (underlined in Figure 1). Fourteen of these are MOT light-stations. The remaining two are: the Pacific Biological Station (of the Department of Fisheries and Environment (DFE)) at Departure Bay, and the meteorological station - of the Atmospheric Environment Service (AES) of DFE - at Cape St. James. Table 1 lists these stations in north-to-south order along the "outside coast" (Langara Island to Race Rocks) and along the Strait of Georgia (Cape Mudge to Active Pass). The general location of each station, as well as the names of the observers that participated during 1977, are also noted.

This report presents the data obtained in 1977 from these sixteen locations.

Observational Equipment and Procedures

Except at Active Pass, each daily observation is made within one hour before (and as near as possible to) the occurrence of the daytime high tide. The exact time, however, is dependent both upon weather conditions and upon the press of the observer's primary duties. At Active Pass, observations are made at daylight high-water slack as obtained from the Canadian Tide and Current Tables (Environment Canada 1977). At no station is sampling ever attempted in darkness.

At each station, the water temperature is measured by means of a mercury-in-glass thermometer. At fifteen of the stations, thermometers recording with the range 10° to 140° Fahrenheit (F), and graduated in 1° intervals, are used. At the remaining station (Departure Bay), a Celsius (C) thermometer of range -10° to 60° and graduated in 0.5° intervals is employed. Before use in the field, each instrument is checked against a calibrated thermometer; the maximum error allowed is ±0.4°F or ±0.2°C. The seawater temperature is estimated to within ±0.1°F or 0.1°C.

The thermometer, (partially) enclosed in a protective case of 1-in. (2.5-cm) aluminum pipe, is attached to the end of a pole (also made of aluminum pipe) which can be as long as about 20 ft (about 6 m) and left at that depth for two minutes. The greatest pole lengths are necessary at sites

where observations are carried out from steep bluffs. At some stations, water samples are obtained by bucket during inclement weather.

At fourteen stations (all except Sheringham Point and Cape St. James[1]) a glass or plastic bottle, usually of about 25-oz (710-cc) capacity, is also attached to the pole. At the same time that the temperature of the water is recorded, a sample is drawn from the bottle for use in the measurements of salinity. (Where a bucket is employed to obtain the seawater, the sample is drawn from the bucket.) At all but one of these fourteen stations, the density of each sample is determined by hydrometer; the salinity is then obtained from this value of density. The hydrometers employed are similar to those used by the U.S. Coast and Geodetic Survey (USC&GS) at its tidal stations[2]; they actually measure the *specific gravity*[3] of a seawater sample. Specific gravity is a ratio of two densities and is therefore a dimensionless quantity. If however, by definition, distilled water at a temperature 39.2°F (4°C) has a density $\rho_m = 1$, then the specific gravity of a substance having density ρ is ρ/ρ_m and will be numerically equal to the value of ρ.

The density (or specific gravity) of a seawater sample depends upon both the quantity of dissolved material in the sample (the "salinity") and the temperature of the sample at the time the measurement is made. Densities determined by hydrometer without temperature control must therefore be reduced to some "standard" temperature for conversion to the corresponding salinities. The standard adopted for this program is 15°C (59°F), the same as that presently used by the USC&GS.

An expression of the general form *Sp. Gr. Tp. (or Temp.)* $\frac{15.4°C}{}$ is provided on every hydrometer utilized in this program. It incorporates both the basis of specific gravity (distilled water at 4°C (39.2°F) and the standard temperature (15°C or 59°F)) employed.

Hydrometers are supplied to the stations in one or more of three ranges of specific gravity: 0.9960 - 1.0110, 1.0100 - 1.0210, and 1.0200 - 1.0310. The scales are divided into intervals of 0.0002, and the instruments are claimed to be accurate to ±0.0001. The hydrometers are read employing techniques described by the USC&GS (Adams, 1942). Each instrument has its calibration checked immediately before being sent to a station.

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1 Measurements of salinity were terminated at Sheringham Point on 31 March 1970 and at Cape St. James on 31 May 1971.

2 Since 1970, the USC&GS has been a component of the National Ocean Surveys of the National Oceanic and Atmospheric Administration (NOAA).

3 It should be noted that the term "specific gravity" has recently been replaced, in scientific usage at least, by the term "relative density".

At Departure Bay, salinities were obtained by hydrometry up to 7 February 1977. Subsequently they have been determined by laboratory salinometer - an Auto-Lab Model 601 Mark III inductive (electrodeless) type. The accuracy of this instrument, using duplicate determinations, is estimated to be ±0.003 parts per thousand (°/₀₀).

It may be noted that comparison determinations involving several dozen samples collected at British Columbia shore stations have indicated that about 85% of the "hydrometer" salinity values obtained were within ±0.3°/₀₀ of the corresponding ones obtained by salinometer (Hollister, unpublished). Because of the greater accuracy of the salinometer-determined values, post-February 7th salinities at Departure Bay are recorded to two places of decimals, rather than to only one as is the case for values obtained by hydrometer.

The time of each daily observation, as well as the associated seawater temperature and hydrometer or salinometer readings, are recorded on monthly field sheets. The sheets are mailed to the Pacific Environment Institute, West Vancouver, British Columbia - usually every two months - for preliminary processing.

Preliminary Processing of the Data

The temperature data are scanned, and values are rejected if it is discovered that a faulty thermometer has been used, or if the value is obviously the result of a misreading or of any other error in technique. The observed hydrometer readings are reduced to densities at the standard temperature, 15°C (59°F), by means of tables prepared by the USC&GS (Zerbe and Taylor, 1953). The appropriate calibration correction is then applied to each such density value. These corrected values are in turn converted to salinities. A salinity value is rejected, again, only if it obviously results from a misreading of hydrometer or salinometer or from other procedural errors.

If observations are missing for *one* day or for *two consecutive* days, the resulting gap is filled by value(s) obtained by linear interpolation utilizing the two observations bounding the gap. No interpolated values are provided when readings have been missed for *three or more* consecutive days (whether by accident or by design).

Machine Processing of Data

For each calendar year, the daily temperature and salinity data remaining after the preliminary procedures noted above are processed into final form by the Marine Environmental Data Services Branch (MEDS) of Ocean and Aquatic Sciences (OAS), DFE in Ottawa. For each station, this computer processing involves the determination of the twelve monthly means for temperature and for salinity, as well as of the corresponding standard deviations. The annual means are also computed. All means are rounded off to the first decimal place, and the standard deviations are truncated at the second decimal place. Data obtained by interpolation are *not* utilized in the computation of the means.

A form of smoothing has been performed on the data to minimize the effect of any variability associated with frequencies large compared to the annual frequency (those associated with tides, for example). For simplicity, the daily values of salinity and/or temperature at each sampling station are here considered to be equally spaced in time - with a sampling interval, therefore, of 24 hours. A seven-day, normally-weighted running mean (Holloway, 1958) has been utilized to smooth the resulting series; this form of filtering is considered to result in an output free of such defects as "polarity reversals" or phase shifts. The running mean is computed, for the entire year, for both temperature and salinity. In order that these means for each station be as continuous as possible consistent with the data involved, interpolated daily values *have* been utilized in the associated computations. However when a period of greater than *two* consecutive days of missed data is encountered the computations will be interrupted.

Presentation of the Data

The data from each station are presented in two forms:

(1) Tabulations, in monthly format, of the daily values of temperature in °F and of salinity in parts per thousand (°/₀₀) - pages 14 to 77. The results are listed in the same station order as that given in Table 1. Three months' data are listed on each page. Also recorded for each month are the mean, the standard deviation (STD.DEV.), the number of observations (OBSVNS.) involved in the computations of these two quantities, and the maximum and minimum values. The *annual* means (YRLY. MEANS) for temperature and salinity are included with the December output for each station. Each interpolated daily value is identified by an asterisk (*). "Missed" values with which no interpolation is associated are denoted by a "*0.0" entry. Invalid days, such as April 31, are indicated by a "0.0" entry. Both the latitude and longitude of each station (in degrees, minutes and seconds) are noted on every page, immediately after the station designation. For ease in reference, the monthly- and annual-mean temperatures and salinities are summarized in Tables 2 and 3 respectively. Temperatures in Table 2 are the Celsius (°C) equivalents, rounded to the first decimal place, of those given in the tabulations; they are provided here for completeness, in deference to the almost-universal use of the Celsius system of temperature measurement in present-day marine science.

(2) "Annual" graphs of the seven-day, normally-weighted running mean for temperature and salinity - pages 80 to 111. These graphs are copies of the computer-generated plots of the means - reduced for display on present-size pages. Any interruption - due to missing data - in the associated computations will result in a gap in the plotted output as well. Each graph for temperature is provided with scales in both °F and °C.

Several features associated with the data presented should be noted:

(a) At Departure Bay, circumstances beyond the control of the program have rendered it impossible - from May 1974 onward - to carry out observations on weekends (Saturdays and Sundays) and on statutory holidays. The maximum number of (non-interpolated) values available for determination of each monthly mean has therefore been reduced from,

approximately, thirty to twenty at this station. The running-mean calculations have suffered accordingly.

(b) At Cape Mudge, the number of (non-interpolated) daily values was reduced to the low twenties or less during several months; observers were hampered at such times by extremely rough seas. The same problem occurred at Cape St. James, although to a somewhat lesser degree.

(c) At Active Pass, the daily salinity values (and the associated running means) during June through August of each year are in general relatively low - quite often < 20°/₀₀. The salinity range utilized for the running-mean graph at Active Pass (page 111) has therefore been chosen to be 16 to 30°/₀₀, rather than the 20 to 34°/₀₀ range employed elsewhere. It is felt that the *variability* in the mean during the three-month period can thus be better displayed.

(d) At Langara and Kains Islands, several salinity values of 33°/₀₀ or more were recorded during 1977 - primarily in April (Langara) and in August (Kains). All physical-oceanographic studies so far conducted indicate that such values are extremely unlikely in the nearshore surface waters of British Columbia. Observers at the two stations had been apprised of this fact and therefore checked both equipment and procedures thoroughly during the high-value periods. No obvious faults or errors were revealed, and the problem therefore remains unresolved. However, the high values should still be regarded with extreme caution. They have *not* been included in the computations of monthly means, but have been retained in the running-mean output.

Acknowledgements

The sea-sampling program at British Columbia shore stations owes its success primarily to the dedication of the many observers who are taking, or have taken, part in the obtaining of the data. These observers have maintained a remarkable continuity of effort, often in the face of extremely hazardous sea and weather conditions. The several vital contributions of MOT to the program are gratefully acknowledged: the provision of the voluntary sources of the lightkeepers as observers, as well as the excellent assistance received from the District Managers and staffs of the Marine Transportation Division in Victoria and in Prince Rupert, and from its Radio Branch, which transmits the numerous messages involved in the program. The services of the meteorological staff at Cape St. James have been made available to the program through the kind permission of the Regional Director of the Pacific Region of AES. The computations on the data were carried out by the Data Processing and Analysis Section of MEDS under the guidance of Mr. A.E. King. The observers receive a payment from Ocean and Aquatic Sciences, DFE, for their efforts on behalf of the program.

References

Adams, K.T. 1942. Hydrographic manual. Rev. ed. U.S. Coast and Geodetic Survey. Special Publication No. 143.

Environment Canada. 1977. Canadian Tide and Current Tables, Volume 5. Juan de Fuca and Georgia Straits. Fisheries and Marine Service, Ottawa.

Hollister, H.J. and A.M. Sandnes. 1972. Sea surface temperature and salinities at shore stations on the British Columbia coast, 1914-1970. Pacific Marine Science Report 72-13. Environment Canada, Marine Sciences Directorate, Pacific Region, Victoria, B.C.

Holloway, J.L., Jr. 1958. Smoothing and filtering of time series and space fields. In: Advances in Geophysics, Vol. 4. pp. 351-389. Academic Press Inc., New York.

Somers, H. 1965. Program G20106, daily seawater observations. Memorandum 1220-2-4/April 30, 1965. Canadian Oceanographic Data Centre, Special Administrative Services Division, Ottawa.

Zerbe, W.B. and C.B. Taylor. 1953. Sea water temperature and density reduction tables. U.S. Coast and Geodetic Survey. Special Publication No. 298.

Figure 1. Location of B.C. shore stations making daily oceanographic observations (1977) reported in this publication.

Table 1. B.C. shore stations providing the oceanographic data reported in this publication: general locations, and names of observers.

STATION	LOCATION	OBSERVER(S)
Outside Coast		
Langara Island	Dixon Entrance south side	L. Sabourin (Mrs.) J.E. Redhead (Mrs.)
Bonilla Island	Hecate Strait, north	M. Slater B. Jones T. McKay
McInnes Island	Milbanke Sound entrance, north side	F.M. Collette (Mrs.) K. Coldwell (Mrs.)
Cape St. James	Queen Charlotte Islands, south end	D.S. Robinson (Mrs.) C. Hilliar
Egg Island	Smith Sound, southern entrance	K. Carson (Mrs.) K. Ashe (Mrs.)
Pine Island	Queen Charlotte Strait, western entrance	V.C. Emrich (Mrs.) E.M. Chapman (Mrs.) K. Watson (Mrs.)
Kains Island	Quatsino Sound entrance, north side	L.C. Collins (Mrs.)
Amphitrite Point	Barkley Sound, western entrance	I.G. McNeil J.K. Nuttall D. Chapman E.M. Chapman (Mrs.) M.V. Stewart (Mrs.)
Sheringham Point	Juan de Fuca Strait, northern shore	E.S. Bruton (Mrs.)
Race Rocks	Juan de Fuca Strait, eastern end	F.B. Anderson (Mrs.)
Strait of Georgia		
Cape Mudge	Strait of Georgia, northern entrance	R. Wilke G. Milum

Table 1 continued

Station	Location	Observer(s)
Strait of Georgia		
Sisters Island	Strait of Georgia, central	D.J. McNeil W. Milne R.J. Grunert T.G. Smith
Chrome Island	Strait of Georgia, central western shore	W.E. Gardner F. McWilliams
Departure Bay	Strait of Georgia, central western shore	A. Ballantyne (Mrs.) A. Acara D. Pozar
Entrance Island	Strait of Georgia, central western shore	E. Cehak (Mrs.)
Active Pass	Strait of Georgia, southwestern shore	J.E. Ruck

Table 2. Monthly- and annual-mean temperatures (°C) - 1977

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Langara I.	7.6	7.7	7.2	7.3	8.4	10.4	11.7	11.6	11.9	10.9	7.7	6.0	9.1
Bonilla I.	6.9	7.6	7.3	8.0	9.9	11.6	12.6	12.4	11.8	10.4	8.2	6.3	9.4
McInnes I.	6.4	7.3	7.2	8.2	9.4	10.9	12.3	14.4	13.5	11.0	8.1	6.8	9.7
Cape St. James	8.1	8.2	7.9	8.0	8.8	10.1	10.7	12.4	12.4	10.0	8.6	7.6	9.6
Egg I.	6.9	7.8	7.3	8.6	10.2	11.7	13.3	13.8	10.9	9.8	8.3	7.2	9.7
Pine I.	7.9	8.1	7.8	7.9	8.3	9.1	9.4	9.8	9.6	9.6	8.6	7.7	8.6
Kains I.	8.2	8.6	8.4	9.2	10.3	11.4	12.6	13.7	13.2	11.8	9.3	8.0	10.4
Amphitrite Pt.	7.8	8.4	8.6	9.7	10.7	11.9	11.9	14.4	13.4	11.9	9.3	8.3	10.6
Sheringham Pt.	7.6	7.8	8.1	8.6	9.1	9.9	10.6	11.3	10.8	9.7	8.9	7.9	9.2
Race Rocks	7.6	7.9	8.1	8.3	8.8	9.8	10.0	10.9	10.3	9.3	8.6	7.9	9.0
Cape Mudge	7.4	7.9	8.2	9.4	11.1	13.5	14.7	14.7	12.5	10.3	8.3	7.7	10.6
Sisters I.	6.8	7.5	7.6	9.2	12.3	14.9	17.2	18.1	14.1	11.2	8.6	7.1	11.3
Chrome I.	7.2	8.0	7.7	9.1	11.2	14.6	16.1	18.1	14.1	11.2	8.4	7.4	11.1
Departure Bay	6.7	8.0	8.0	10.1	12.2	15.8	17.0	17.9	14.5	11.3	8.1	6.2	11.6
Entrance I.	6.8	7.4	7.8	9.3	11.6	14.7	16.4	16.9	14.1	11.2	8.7	6.7	11.0
Active Pass	6.8	7.6	7.7	9.3	10.2	13.2	14.2	16.1	13.7	11.1	8.3	6.7	10.4

Table 3. Monthly- and annual-mean salinities (°/₀₀) - 1977

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Langara I.	32.3	32.5	32.5	32.4	32.3	32.0	32.3	32.5	32.2	32.1	31.8	31.8	32.2
Bonilla I.	30.9	31.1	30.9	31.1	31.1	31.1	31.3	31.3	31.5	31.5	30.9	31.1	31.2
McInnes I.	29.1	30.0	30.0	30.2	30.4	30.7	29.9	30.2	30.5	31.1	30.2	30.8	30.2
Egg I.	30.7	30.7	30.7	31.3	30.8	31.0	28.4	29.7	31.2	31.4	30.9	30.5	30.6
Pine I.	31.3	31.3	31.2	31.1	31.2	31.3	31.7	31.6	31.5	31.7	31.0	30.8	31.3
Kains I.	30.2	30.1	29.3	30.6	31.1	31.9	32.2	32.5	31.9	31.2	29.0	29.1	30.7
Amphitrite Pt.	29.2	29.3	28.8	29.1	30.0	30.5	31.6	31.3	30.6	30.5	28.3	27.2	29.7
Race Rocks	31.2	31.4	30.9	31.6	31.5	31.2	31.5	31.0	31.3	31.7	31.5	30.7	31.3
Cape Mudge	29.0	29.2	29.0	29.3	29.1	28.8	26.9	27.2	27.9	28.4	28.2	28.5	28.4
Sisters I.	29.1	29.5	29.2	29.9	27.9	25.7	25.5	26.0	27.6	28.9	29.4	28.8	28.1
Chrome I.	29.2	29.1	29.3	30.0	29.7	28.4	28.2	27.4	28.5	29.2	28.7	29.0	28.9
Departure Bay	27.6	28.3	27.4	28.3	26.2	25.0	24.4	25.6	26.4	27.9	26.9	25.1	26.4
Entrance I.	27.8	27.8	28.9	29.3	26.6	25.0	24.5	25.5	26.2	28.0	27.7	26.8	27.0
Active Pass	27.2	28.2	28.4	27.7	28.5	25.5	25.1	24.6	25.7	27.7	28.4	26.5	27.0

Tabulations of Daily Sea-surface

Temperature and Salinity

1977

TEMP:	Temperature (°F)
SAL:	Salinity (°/₀₀)

LANGARA ISLAND 54 15 19 N 133 03 30 W

DATE	JANUARY TEMP	JANUARY SAL	FEBRUARY TEMP	FEBRUARY SAL	MARCH TEMP	MARCH SAL 1977
1	* 46.0	* 32.5	45.0	32.3	45.0	32.1
2	45.7	32.7	46.1	32.4	47.2	32.4
3	45.2	31.6	44.0	32.7	* 46.2	* 32.6
4	45.6	32.4	46.5	32.4	45.2	32.7
5	45.2	32.5	46.3	32.5	45.2	32.8
6	45.7	31.8	48.2	32.5	45.1	32.4
7	45.1	31.8	46.0	32.8	46.0	** 33.2
8	44.9	32.3	46.1	* 33.2	45.0	32.8
9	45.4	32.1	46.0	32.4	45.1	32.7
10	45.1	31.8	45.9	32.7	43.0	32.8
11	45.2	32.3	46.0	32.5	44.7	32.8
12	45.2	32.0	45.8	32.5	44.9	** 33.2
13	45.4	32.0	46.2	32.8	44.5	32.7
14	46.7	32.3	46.9	32.5	44.9	32.7
15	46.3	32.0	46.0	32.5	45.0	32.4
16	46.7	32.0	46.1	32.8	45.2	32.5
17	46.5	32.3	46.0	32.7	45.1	32.4
18	* 46.9	* 32.4	46.1	32.7	44.7	32.4
19	47.3	32.5	46.2	32.8	44.9	32.5
20	46.9	32.5	47.3	32.5	44.7	32.7
21	46.4	32.5	45.8	32.5	45.1	32.4
22	46.0	32.5	46.2	32.8	44.8	32.7
23	46.0	32.7	45.8	32.8	44.9	32.7
24	46.0	32.5	44.5	30.8	44.8	32.5
25	45.3	32.7	45.7	32.3	45.2	32.8
26	44.0	32.4	44.8	32.4	44.8	32.0
27	44.2	32.1	44.7	32.4	44.0	32.4
28	44.0	32.4	45.0	32.5	43.9	32.3
29	* 44.6	* 32.6	0.0	0.0	44.0	32.3
30	45.2	32.8	0.0	0.0	45.0	31.6
31	46.1	32.5	0.0	0.0	44.9	31.6
MEANS	45.6	32.3	45.9	32.5	44.9	32.5
OBSVNS.	26	28	28	27	30	28
MAXIMUM	47.3	32.8	48.2	32.8	47.2	32.8
MINIMUM	44.0	31.6	44.0	30.8	43.0	31.6
STD.DEV.	.83	.32	.84	.38	.66	.33

LANGARA ISLAND 54 15 19 N 133 03 30 W

	APRIL		MAY		JUNE	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	45.4	31.9	46.2	32.3	50.0	32.0
2	44.8	31.5	46.0	32.3	49.5	31.9
3	45.1	32.0	46.4	32.7	49.9	32.0
4	44.7	32.8	47.0	32.5	51.0	32.0
5	45.2	32.5	47.0	32.5	49.0	32.0
6	45.2	32.3	46.8	32.4	50.0	32.1
7	45.0	32.8	46.4	32.4	49.8	31.9
8	45.5	32.9	46.2	32.5	50.0	31.5
9	45.0	32.7	46.7	32.3	49.9	31.8
10	45.3	32.7	46.7	32.0	50.3	31.8
11	44.9	31.0	* 46.5	* 32.0	51.1	32.3
12	45.0	31.8	46.2	31.9	50.0	32.3
13	44.5	32.3	46.4	32.4	50.3	32.0
14	44.0	32.3	46.5	32.3	50.1	32.5
15	44.8	32.1	46.2	32.0	51.1	32.4
16	44.9	32.5	47.2	31.6	49.9	32.4
17	44.2	32.4	47.6	32.7	49.8	31.9
18	45.0	32.5	48.0	32.3	50.7	31.6
19	44.9	32.8	48.2	31.9	51.0	31.6
20	45.2	** 33.0	47.2	32.4	52.3	32.0
21	45.5	32.7	48.0	32.7	51.0	32.4
22	45.7	** 33.2	47.0	32.3	52.1	32.0
23	45.7	** 33.4	47.2	31.9	50.8	32.5
24	46.0	** 33.0	48.2	32.3	51.9	32.5
25	46.3	** 33.2	47.9	32.1	51.4	32.4
26	46.4	** 33.3	48.4	32.3	51.0	31.9
27	46.0	32.5	48.1	32.8	51.0	32.3
28	45.4	32.7	47.2	32.5	52.0	31.9
29	45.6	32.4	48.2	32.5	52.4	31.4
30	46.0	32.8	48.0	32.8	51.8	31.5
31	0.0	0.0	48.4	32.5	0.0	0.0
MEANS	45.2	32.4	47.2	32.3	50.7	32.0
OBSVNS.	30	24	30	30	30	30
MAXIMUM	46.4	32.9	48.4	32.8	52.4	32.5
MINIMUM	44.0	31.0	46.0	31.6	49.0	31.4
STD.DEV.	.57	.46	.79	.29	.90	.32

LANGARA ISLAND 54 15 19 N 133 03 30 W

	JULY		AUGUST		SEPTEMBER 1977	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	52.1	31.8	52.1	32.5	53.8	32.7
2	51.5	32.8	53.0	32.4	52.2	* 32.7
3	51.6	32.3	54.8	32.5	* 53.1	* 32.8
4	51.0	32.1	53.1	32.3	54.0	32.3
5	52.0	32.3	53.5	32.0	56.0	32.3
6	53.7	32.5	54.8	32.4	57.0	32.3
7	54.8	32.4	54.0	32.4	56.1	32.3
8	54.9	32.3	54.3	32.3	57.0	32.1
9	54.3	32.4	54.2	32.3	56.0	32.5
10	53.0	32.7	56.1	32.7	57.1	32.0
11	53.2	32.5	56.2	32.5	55.8	32.3
12	54.0	30.8	54.3	32.5	54.9	31.9
13	53.9	31.4	52.0	32.7	54.6	32.4
14	53.5	31.5	53.1	32.1	53.0	31.9
15	53.4	32.5	51.0	32.7	53.2	32.0
16	52.0	31.4	* 50.9	* 32.8	51.1	30.2
17	53.0	31.8	50.7	32.9	51.0	32.5
18	53.0	32.3	50.2	32.8	51.1	32.7
19	52.1	32.4	51.8	32.8	52.0	32.1
20	53.1	32.4	51.0	32.8	53.1	32.5
21	52.0	32.8	51.9	32.5	51.9	32.3
22	52.3	32.8	53.0	32.5	54.0	32.0
23	* 53.1	* 32.8	51.0	32.8	52.0	32.3
24	54.0	32.7	52.0	* 33.3	52.7	32.8
25	53.2	32.9	* 51.1	* 33.3	52.5	32.4
26	53.9	32.7	50.2	* 33.2	51.8	32.3
27	54.0	32.5	52.1	* 33.0	52.9	31.9
28	54.1	32.3	52.0	32.8	50.8	32.4
29	55.0	32.8	53.0	* 33.0	50.9	32.4
30	52.0	32.8	* 53.4	* 32.5	51.4	32.4
31	51.9	32.7	53.9	32.0	0.0	0.0
MEANS	53.1	32.3	52.8	32.5	53.4	32.2
OBSVNS.	30	30	28	24	29	28
MAXIMUM	55.0	32.9	56.2	32.9	57.1	32.8
MINIMUM	51.0	30.8	50.2	32.0	50.8	30.2
STD.DEV.	1.08	.51	1.64	.26	2.04	.46

LANGARA ISLAND 54 15 19 N 133 03 30 W

	OCTOBER		NOVEMBER		DECEMBER	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	51.2	32.8	* 47.8	* 31.5	45.0	31.9
2	51.8	32.3	47.4	31.1	45.3	31.6
3	51.9	32.5	47.5	31.5	45.3	31.2
4	52.9	32.1	48.0	31.8	43.2	30.8
5	53.2	32.3	47.7	31.8	42.0	31.9
6	53.1	32.4	47.3	31.4	41.2	32.5
7	52.3	31.8	47.1	31.5	40.9	32.0
8	52.3	32.5	46.3	31.2	* 39.9	* 32.0
9	51.9	32.4	45.3	31.5	38.9	32.1
10	52.1	31.8	47.0	31.9	39.3	32.0
11	54.0	31.5	46.4	31.6	43.1	32.0
12	52.0	32.1	47.2	31.4	42.5	31.6
13	52.8	32.7	46.8	31.8	* 42.8	* 31.3
14	52.4	32.3	47.3	32.4	43.1	31.0
15	53.0	32.3	47.0	31.5	43.8	32.3
16	51.9	32.5	46.2	31.5	41.7	31.9
17	52.3	31.9	45.4	31.5	42.0	30.2
18	52.1	32.5	44.5	32.5	42.9	31.0
19	50.9	32.0	44.2	32.7	42.7	31.8
20	51.0	32.5	42.7	31.6	44.2	31.9
21	* 51.4	* 32.2	42.9	32.4	43.7	31.9
22	51.9	31.9	42.4	32.5	43.2	32.1
23	51.0	32.4	* 42.7	* 32.3	42.1	32.0
24	49.6	32.4	43.0	32.0	41.9	32.0
25	50.0	32.1	44.9	32.0	43.1	32.7
26	50.7	31.8	44.0	31.6	43.8	32.1
27	* 50.4	* 31.5	46.2	31.9	43.0	32.5
28	50.1	31.2	45.8	32.1	43.7	32.4
29	50.0	31.9	45.7	32.3	44.4	31.9
30	49.8	31.6	45.1	31.9	43.2	32.0
31	48.2	31.8	0.0	0.0	41.9	32.0
MEANS	51.6	32.1	45.8	31.8	42.8	31.8
OBSVNS.	29	29	28	28	29	29
YRLY.MEANS......................................					48.3	32.2
MAXIMUM	54.0	32.8	48.0	32.7	45.3	32.7
MINIMUM	48.2	31.2	42.4	31.1	38.9	30.2
STD.DEV.	1.30	.38	1.65	.42	1.52	.54

BONILLA ISLAND 53 29 39 N 130 38 04 W

	JANUARY		FEBRUARY		MARCH	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	44.8	31.2	45.0	31.2	45.1	30.8
2	45.0	31.4	45.2	31.1	44.2	31.0
3	44.8	31.2	45.6	31.2	45.2	30.7
4	44.7	31.5	46.0	30.8	45.2	30.4
5	43.2	31.2	45.2	31.2	45.9	31.0
6	44.5	30.8	45.9	30.4	44.2	30.6
7	44.2	30.7	45.4	30.7	45.1	30.7
8	44.0	30.4	45.6	30.4	45.3	30.8
9	43.8	30.4	45.2	30.8	45.8	31.2
10	43.8	30.6	45.1	31.1	44.6	31.1
11	44.0	30.7	45.4	31.0	45.3	31.0
12	43.8	30.7	45.8	31.2	45.0	31.1
13	43.4	30.6	45.9	30.8	44.0	30.7
14	43.8	30.7	45.9	30.7	44.2	30.7
15	44.9	30.6	45.8	31.4	45.0	31.4
16	44.8	30.4	46.1	31.5	45.7	30.7
17	45.8	30.7	46.2	31.6	45.2	31.2
18	45.0	30.7	46.1	31.6	45.1	31.1
19	45.4	30.7	46.8	31.6	45.9	31.1
20	45.5	30.8	46.3	31.5	46.0	31.1
21	44.8	30.7	46.0	31.4	45.8	31.0
22	45.2	30.7	46.0	31.5	45.3	30.8
23	44.8	30.8	* 45.7	* 31.5	45.1	30.8
24	44.9	31.0	45.4	31.5	45.9	31.0
25	44.8	31.1	45.0	31.0	45.0	30.6
26	44.3	31.5	44.4	30.7	45.2	31.1
27	44.0	31.2	44.6	30.7	45.2	31.0
28	44.1	31.1	45.0	31.2	44.8	31.2
29	43.9	31.1	0.0	0.0	43.9	30.8
30	43.6	30.7	0.0	0.0	44.1	31.0
31	44.8	31.0	0.0	0.0	45.0	30.8
MEANS	44.5	30.9	45.6	31.1	45.1	30.9
OBSVNS.	31	31	27	27	31	31
MAXIMUM	45.8	31.5	46.8	31.6	46.0	31.4
MINIMUM	43.2	30.4	44.4	30.4	43.9	30.4
STD.DEV.	.65	.31	.56	.37	.60	.22

BONILLA ISLAND 53 29 39 N 130 38 04 W

	APRIL		MAY		JUNE	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	45.7	31.0	49.1	31.5	55.0	31.1
2	45.9	31.1	47.2	31.0	54.5	31.0
3	47.0	31.2	49.3	31.4	55.0	31.1
4	46.3	31.1	49.3	31.2	55.0	31.0
5	47.3	31.2	48.0	30.8	55.0	31.1
6	46.2	31.6	48.5	30.8	55.0	30.8
7	47.3	31.0	48.0	31.1	54.5	31.1
8	45.7	31.1	48.5	31.2	50.3	31.2
9	45.8	31.0	47.0	31.8	50.0	31.2
10	45.0	31.0	47.0	31.5	50.2	31.2
11	45.2	31.4	47.1	31.5	50.8	31.0
12	45.8	30.7	48.0	30.7	50.5	31.2
13	45.3	31.2	48.5	30.8	50.5	31.0
14	43.4	30.4	49.5	31.0	51.5	31.0
15	45.6	30.8	49.5	31.0	54.2	31.0
16	46.2	31.1	48.5	31.1	54.9	31.1
17	46.2	31.4	50.5	31.2	54.2	30.8
18	45.0	31.4	53.0	31.4	53.5	30.8
19	46.8	31.1	51.5	31.0	54.2	30.6
20	48.0	31.2	49.5	30.8	53.4	30.4
21	47.2	31.5	50.5	31.0	52.5	30.8
22	47.2	31.0	54.5	31.0	53.7	31.2
23	* 47.4	* 31.0	53.0	31.0	51.9	30.8
24	47.6	31.0	54.5	30.8	51.8	31.5
25	48.1	31.2	48.2	31.1	51.8	31.5
26	46.9	31.4	49.0	31.4	51.2	31.2
27	46.9	31.1	49.3	31.2	52.1	31.2
28	47.0	31.4	49.0	31.0	51.9	31.1
29	46.8	31.2	53.0	31.0	53.0	31.5
30	48.0	31.2	54.9	30.7	54.8	31.6
31	0.0	0.0	54.8	31.1	0.0	0.0
MEANS	46.4	31.1	49.9	31.1	52.9	31.1
OBSVNS.	29	29	31	31	30	30
MAXIMUM	48.1	31.6	54.9	31.8	55.0	31.6
MINIMUM	43.4	30.4	47.0	30.7	50.0	30.4
STD.DEV.	1.07	.25	2.45	.27	1.76	.26

BONILLA ISLAND 53 29 39 N 130 38 04 W

	JULY		AUGUST		SEPTEMBER 1977	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	54.0	31.6	55.0	31.2	54.3	32.1
2	53.9	31.5	54.5	31.4	53.0	31.8
3	54.2	31.5	54.0	31.6	52.9	31.1
4	54.4	31.4	52.9	31.4	54.9	31.5
5	55.3	31.6	52.8	31.9	55.8	31.5
6	56.7	31.5	52.8	31.5	55.3	31.1
7	54.6	31.8	53.0	31.0	55.6	31.0
8	53.8	31.4	53.5	31.0	54.0	31.4
9	53.0	31.2	57.8	30.0	55.1	31.6
10	52.9	31.4	57.2	30.4	55.3	31.4
11	53.9	31.5	58.9	30.4	56.1	31.2
12	54.1	31.1	55.0	31.0	56.2	31.8
13	54.9	30.8	54.4	31.4	53.9	31.6
14	54.2	31.0	57.1	31.6	51.9	32.0
15	53.9	31.0	52.0	31.6	52.8	31.9
16	53.4	30.8	51.2	31.5	52.2	31.9
17	55.8	31.1	51.5	31.8	51.9	32.0
18	52.9	30.8	52.9	31.8	51.0	31.4
19	55.8	30.8	55.4	31.1	52.2	31.4
20	56.8	31.4	55.2	31.1	52.9	31.4
21	55.3	31.5	53.2	31.4	53.0	31.5
22	55.1	31.4	* 54.2	* 31.3	51.1	31.5
23	54.8	31.6	55.2	31.1	52.0	31.5
24	54.8	31.6	54.6	31.2	51.9	31.2
25	54.9	31.1	55.1	31.1	52.1	31.1
26	53.8	31.5	55.3	31.4	52.0	31.5
27	53.9	31.4	54.0	31.4	51.3	31.5
28	55.0	31.4	53.9	31.1	51.1	31.5
29	* 55.2	* 31.4	* 53.6	* 31.3	51.4	31.4
30	55.5	31.5	53.2	31.5	51.6	31.5
31	56.0	31.1	53.0	31.8	0.0	0.0
MEANS	54.6	31.3	54.3	31.3	53.2	31.5
OBSVNS.	30	30	29	29	30	30
MAXIMUM	56.8	31.8	58.9	31.9	56.2	32.1
MINIMUM	52.9	30.8	51.2	30.0	51.0	31.0
STD.DEV.	1.03	.28	1.82	.44	1.68	.28

BONILLA ISLAND 53 29 39 N 130 38 04 W

	OCTOBER		NOVEMBER		DECEMBER	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	51.7	31.8	49.8	30.7	45.2	30.4
2	53.0	31.4	49.9	31.0	45.0	30.6
3	* 51.8	* 31.5	* 49.4	* 31.0	45.2	30.8
4	50.6	31.6	48.8	31.1	44.2	31.0
5	51.7	31.4	48.6	30.7	41.2	31.0
6	50.0	31.1	48.2	30.6	41.9	31.0
7	50.9	31.6	48.3	30.6	41.9	31.1
8	51.0	31.5	48.0	31.4	42.0	31.2
9	50.5	31.5	48.0	31.5	41.9	31.2
10	49.9	31.2	48.2	31.2	41.7	31.0
11	51.1	31.0	48.7	31.1	44.0	31.0
12	51.9	31.2	48.0	31.1	43.8	31.4
13	52.0	31.1	47.3	30.8	45.0	31.5
14	50.9	31.6	48.1	31.1	45.2	31.2
15	51.9	31.4	48.0	31.0	44.0	31.2
16	51.8	31.6	47.8	31.1	43.1	31.0
17	51.3	32.0	47.8	31.4	43.1	31.0
18	51.1	32.1	47.0	31.2	42.1	30.8
19	50.9	31.9	46.0	31.4	* 42.5	* 30.8
20	49.3	31.6	44.2	31.4	43.0	30.8
21	49.8	31.8	44.8	31.4	43.3	31.0
22	51.0	31.8	43.4	31.1	43.8	31.0
23	51.0	31.8	42.1	30.7	43.3	31.4
24	50.2	31.6	43.2	30.3	42.2	31.0
25	50.8	31.5	44.9	30.2	43.1	31.4
26	49.1	31.6	45.6	30.6	43.5	31.5
27	50.1	31.8	45.9	30.7	43.8	31.1
28	50.2	31.4	45.8	29.9	43.0	31.4
29	49.8	31.1	45.8	30.8	43.7	31.1
30	50.1	31.2	45.1	30.4	43.0	31.4
31	49.9	31.5	0.0	0.0	42.8	31.5
MEANS	50.8	31.5	46.8	30.9	43.3	31.1
OBSVNS.	30	30	29	29	30	30
YRLY.MEANS....................................					48.9	31.2
MAXIMUM	53.0	32.1	49.9	31.5	45.2	31.5
MINIMUM	49.1	31.0	42.1	29.9	41.2	30.4
STD.DEV.	.89	.28	2.02	.41	1.13	.27

MCINNES ISLAND 52 15 48 N 128 43 10 W

	JANUARY		FEBRUARY		MARCH	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	42.3	26.3	44.1	29.5	45.1	30.0
2	43.3	28.2	43.9	29.4	45.0	30.0
3	41.7	27.1	44.2	29.4	44.9	30.0
4	42.0	28.0	44.9	29.9	44.9	29.9
5	42.3	28.5	45.2	29.9	45.1	30.4
6	42.9	28.9	45.3	30.0	45.5	30.4
7	43.0	29.1	45.5	30.2	46.0	31.1
8	42.2	28.4	45.3	30.0	* 45.6	* 31.7
9	42.6	28.9	45.4	30.2	* 45.1	* 30.3
10	43.0	29.1	45.4	30.2	44.6	29.8
11	43.7	29.5	45.5	30.3	* 44.7	* 29.9
12	43.4	29.4	45.4	30.3	44.9	30.0
13	44.1	29.7	* 45.5	* 30.3	44.6	30.0
14	43.8	29.5	45.7	30.3	44.2	29.3
15	44.9	29.8	46.0	30.7	43.9	28.5
16	45.3	29.9	45.2	29.9	43.9	29.1
17	* 45.4	* 29.9	45.5	30.0	44.6	29.7
18	45.5	29.9	45.4	29.8	44.5	29.7
19	45.4	29.9	* 45.4	* 30.0	44.8	29.8
20	45.3	29.9	* 45.5	* 30.2	44.8	29.8
21	45.0	29.9	45.5	30.4	45.1	30.0
22	44.7	29.0	45.5	30.0	45.1	29.8
23	44.4	29.0	45.5	29.9	45.4	30.2
24	43.9	29.1	44.9	29.7	45.5	30.3
25	43.7	29.1	45.7	30.3	45.0	30.0
26	43.8	29.4	45.2	30.2	45.0	30.3
27	43.3	29.4	45.5	30.2	45.1	30.7
28	43.2	29.4	45.4	30.3	44.9	30.2
29	43.3	29.1	0.0	0.0	44.5	30.3
30	43.9	29.7	0.0	0.0	44.8	29.9
31	43.5	29.5	0.0	0.0	45.0	30.0
MEANS	43.6	29.1	45.2	30.0	44.9	30.0
OBSVNS.	30	30	25	25	28	28
MAXIMUM	45.5	29.9	46.0	30.7	46.0	31.1
MINIMUM	41.7	26.3	43.9	29.4	43.9	28.5
STD.DEV.	1.06	.83	.50	.32	.45	.48

MCINNES ISLAND 52 15 48 N 128 43 10 W

	APRIL		MAY		JUNE	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	45.3	30.0	48.5	30.2	51.7	30.4
2	45.6	30.0	47.6	30.2	50.2	30.6
3	46.1	29.8	48.2	30.4	51.4	30.8
4	46.5	29.9	48.0	30.4	50.7	30.3
5	46.8	30.2	48.2	30.4	51.5	30.7
6	46.5	30.0	49.2	30.4	52.2	30.2
7	46.3	30.3	49.6	30.7	52.9	30.2
8	47.0	30.3	48.3	30.4	52.0	30.3
9	46.9	30.4	48.3	30.3	51.5	30.7
10	46.4	30.6	47.3	30.4	51.7	30.3
11	45.7	30.7	47.8	30.3	51.5	30.6
12	46.0	30.8	47.6	30.6	51.2	30.6
13	45.6	30.7	47.7	30.4	51.0	30.7
14	45.8	30.7	47.6	30.6	51.5	30.6
15	46.0	31.0	48.1	30.7	52.2	30.8
16	45.8	31.0	48.9	30.7	51.5	31.0
17	45.8	30.8	48.8	30.4	52.4	31.0
18	45.8	30.7	50.1	30.6	52.7	30.7
19	46.4	30.3	50.0	30.4	53.0	30.8
20	46.9	30.2	49.1	30.6	52.5	31.0
21	47.0	31.0	49.4	30.4	52.8	31.0
22	46.8	29.5	49.6	30.4	52.3	31.0
23	48.9	28.5	50.2	30.3	51.0	30.8
24	49.0	29.5	49.8	30.3	51.0	31.0
25	48.3	29.8	49.4	30.3	50.6	31.1
26	47.4	30.0	49.9	30.4	50.7	31.1
27	46.9	30.3	48.9	30.6	51.2	31.1
28	47.3	30.2	50.4	29.9	51.5	31.2
29	47.8	30.0	51.1	30.2	51.6	31.2
30	48.2	30.2	51.3	30.2	52.1	30.6
31	0.0	0.0	51.6	30.2	0.0	0.0
MEANS	46.7	30.2	49.0	30.4	51.7	30.7
OBSVNS.	30	30	31	31	30	30
MAXIMUM	49.0	31.0	51.6	30.7	53.0	31.2
MINIMUM	45.3	28.5	47.3	29.9	50.2	30.2
STD.DEV.	.98	.53	1.17	.18	.73	.30

MCINNES ISLAND 52 15 48 N 128 43 10 W

	JULY		AUGUST		SEPTEMBER 1977	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	52.1	30.8	56.0	29.7	58.2	31.1
2	52.4	30.8	56.8	30.0	57.3	31.0
3	53.3	30.4	57.2	29.8	58.4	29.9
4	54.4	30.0	57.6	29.9	58.6	30.2
5	54.6	29.5	57.7	29.0	57.8	31.1
6	55.6	29.3	56.2	29.8	58.2	31.0
7	53.5	29.5	57.0	29.7	58.6	30.3
8	53.3	29.5	57.2	29.7	58.0	30.8
9	53.0	29.7	58.0	29.9	57.8	31.1
10	52.4	29.7	59.2	29.9	59.0	31.0
11	52.8	30.3	59.6	30.3	58.2	30.8
12	53.2	30.2	54.4	30.6	57.8	29.9
13	53.7	29.8	56.8	30.0	57.4	30.0
14	54.0	30.2	59.6	30.0	56.7	30.3
15	52.7	30.2	60.2	28.0	55.7	30.3
16	52.8	30.2	59.0	30.0	54.7	30.7
17	53.6	30.8	56.3	30.0	56.0	30.7
18	52.9	29.8	57.3	29.9	55.2	30.4
19	55.3	29.5	55.5	30.2	54.8	29.5
20	55.0	28.9	* 57.7	* 30.4	54.2	30.0
21	55.2	29.4	59.9	30.6	55.0	29.5
22	55.7	29.3	59.6	31.1	55.8	31.0
23	53.3	29.8	59.0	31.0	53.9	31.0
24	54.0	30.2	* 59.4	* 31.1	54.2	30.7
25	55.1	29.4	59.9	31.2	54.2	30.6
26	55.3	29.4	59.1	30.7	55.3	30.6
27	55.0	29.7	58.3	30.8	54.5	30.7
28	55.0	29.9	59.3	31.0	54.2	30.6
29	56.1	30.2	58.4	31.0	54.3	30.4
30	56.7	30.4	58.4	31.0	54.4	30.7
31	56.4	30.4	57.7	30.8	0.0	0.0
MEANS	54.1	29.9	58.0	30.2	56.3	30.5
OBSVNS.	31	31	29	29	30	30
MAXIMUM	56.7	30.8	60.2	31.2	59.0	31.1
MINIMUM	52.1	28.9	54.4	28.0	53.9	29.5
STD.DEV.	1.29	.49	1.49	.70	1.75	.46

MCINNES ISLAND 52 15 48 N 128 43 10 W

	OCTOBER		NOVEMBER		DECEMBER	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	54.2	30.8	48.9	30.8	46.2	30.4
2	54.3	30.7	47.8	30.7	45.2	30.3
3	53.8	31.0	48.6	30.6	44.5	30.2
4	53.2	31.0	47.8	29.4	44.0	31.0
5	* 53.2	* 30.9	47.3	29.0	43.8	30.0
6	53.2	30.7	47.3	29.3	* 0.0	* 0.0
7	53.3	30.8	48.4	31.4	* 0.0	* 0.0
8	52.2	30.6	48.0	31.1	* 0.0	* 0.0
9	52.4	31.0	47.4	30.2	* 0.0	* 0.0
10	52.4	30.8	47.8	30.4	* 0.0	* 0.0
11	52.4	30.7	48.4	30.6	* 0.0	* 0.0
12	52.8	31.5	48.6	30.6	45.2	31.4
13	52.0	30.8	* 48.5	* 30.7	46.2	31.5
14	51.8	30.8	* 48.4	* 30.9	46.2	31.5
15	* 52.0	* 31.0	48.2	31.1	46.1	31.5
16	52.2	31.2	47.4	30.4	45.2	31.5
17	51.8	31.4	46.3	30.0	44.6	31.2
18	51.5	31.6	45.0	28.8	44.3	31.0
19	51.7	31.6	44.2	29.1	44.3	30.7
20	51.0	31.4	43.8	29.8	44.6	30.4
21	50.8	31.4	43.7	29.4	44.5	30.2
22	50.7	31.2	43.2	29.1	43.7	30.4
23	50.7	31.5	43.0	29.0	42.5	30.2
24	50.3	31.9	44.2	30.2	43.0	30.3
25	* 50.3	* 31.9	44.6	30.0	42.8	30.2
26	50.4	31.9	45.4	30.8	43.0	30.8
27	* 50.2	* 31.5	* 45.7	* 30.6	42.8	30.8
28	* 50.0	* 31.1	46.0	30.3	42.8	31.0
29	49.7	30.6	47.2	31.5	43.6	31.2
30	49.7	30.7	46.2	30.7	42.5	30.8
31	49.4	30.6	0.0	0.0	42.8	30.8
MEANS	51.8	31.1	46.5	30.2	44.2	30.8
OBSVNS.	26	26	27	27	25	25
YRLY.MEANS..					49.5	30.2
MAXIMUM	54.3	31.9	48.9	31.5	46.2	31.5
MINIMUM	49.4	30.6	43.0	28.8	42.5	30.0
STD.DEV.	1.38	.41	1.88	.79	1.23	.49

CAPE ST JAMES 51 56 18 N 131 00 50 W

	JANUARY		FEBRUARY		MARCH	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	46.5	* 0.0	46.9	* 0.0	46.6	* 0.0
2	46.3	* 0.0	46.9	* 0.0	46.3	* 0.0
3	46.4	* 0.0	46.7	* 0.0	* 46.6	* 0.0
4	46.3	* 0.0	* 45.8	* 0.0	46.9	* 0.0
5	46.8	* 0.0	47.0	* 0.0	46.2	* 0.0
6	47.0	* 0.0	* 46.9	* 0.0	* 0.0	* 0.0
7	46.8	* 0.0	46.8	* 0.0	* 0.0	* 0.0
8	46.6	* 0.0	* 46.7	* 0.0	* 0.0	* 0.0
9	46.7	* 0.0	46.5	* 0.0	46.2	* 0.0
10	46.5	* 0.0	* 0.0	* 0.0	* 46.2	* 0.0
11	46.9	* 0.0	* 0.0	* 0.0	* 46.1	* 0.0
12	46.5	* 0.0	* 0.0	* 0.0	46.1	* 0.0
13	46.7	* 0.0	* 0.0	* 0.0	46.2	* 0.0
14	47.1	* 0.0	* 0.0	* 0.0	46.4	* 0.0
15	46.8	* 0.0	46.7	* 0.0	46.1	* 0.0
16	* 46.8	* 0.0	* 46.6	* 0.0	46.1	* 0.0
17	* 46.9	* 0.0	46.5	* 0.0	46.0	* 0.0
18	47.0	* 0.0	* 0.0	* 0.0	46.0	* 0.0
19	* 47.0	* 0.0	* 0.0	* 0.0	46.2	* 0.0
20	47.0	* 0.0	* 0.0	* 0.0	46.3	* 0.0
21	* 46.6	* 0.0	* 0.0	* 0.0	46.7	* 0.0
22	46.6	* 0.0	46.6	* 0.0	46.2	* 0.0
23	46.7	* 0.0	46.9	* 0.0	* 46.2	* 0.0
24	46.5	* 0.0	* 46.9	* 0.0	46.1	* 0.0
25	46.5	* 0.0	* 46.8	* 0.0	46.1	* 0.0
26	46.5	* 0.0	46.7	* 0.0	45.7	* 0.0
27	46.3	* 0.0	46.9	* 0.0	45.7	* 0.0
28	46.2	* 0.0	46.8	* 0.0	45.8	* 0.0
29	46.4	* 0.0	0.0	0.0	46.0	* 0.0
30	46.2	* 0.0	0.0	0.0	46.6	* 0.0
31	* 46.5	* 0.0	0.0	0.0	46.0	* 0.0
MEANS	46.6	0.0	46.8	0.0	46.2	0.0
OBSVNS.	26	0	13	0	24	0
MAXIMUM	47.1	0.0	47.0	0.0	46.9	0.0
MINIMUM	46.2	0.0	46.5	0.0	45.7	0.0
STD.DEV.	.26	0.00	.16	0.00	.29	0.00

CAPE ST JAMES 51 56 18 N 131 00 50 W

		APRIL					MAY					JUNE		1977
DATE		TEMP		SAL		TEMP		SAL		TEMP		SAL		
1		46.2	*	0.0		46.9	*	0.0		49.0	*	0.0		
2		46.7	*	0.0		46.7	*	0.0		48.6	*	0.0		
3		46.5	*	0.0		47.1	*	0.0		51.7	*	0.0		
4		46.7	*	0.0		47.2	*	0.0	*	50.4	*	0.0		
5		47.1	*	0.0		47.4	*	0.0		49.0	*	0.0		
6		46.5	*	0.0		47.9	*	0.0		48.9	*	0.0		
7		46.7	*	0.0		47.9	*	0.0		48.9	*	0.0		
8	*	46.5	*	0.0		47.8	*	0.0		48.8	*	0.0		
9	*	46.3	*	0.0	*	47.5	*	0.0		49.3	*	0.0		
10		46.1	*	0.0		47.1	*	0.0		49.2	*	0.0		
11		46.2	*	0.0		46.9	*	0.0		50.4	*	0.0		
12	*	45.9	*	0.0		47.2	*	0.0	*	50.5	*	0.0		
13		45.5	*	0.0		46.9	*	0.0		50.6	*	0.0		
14	*	45.5	*	0.0		47.3	*	0.0		51.0	*	0.0		
15		45.4	*	0.0	*	47.6	*	0.0		51.0	*	0.0		
16		45.7	*	0.0	*	48.0	*	0.0		50.6	*	0.0		
17		45.5	*	0.0		48.4	*	0.0	*	50.7	*	0.0		
18	*	45.9	*	0.0		48.5	*	0.0		50.8	*	0.0		
19		46.4	*	0.0		48.1	*	0.0		51.4	*	0.0		
20		46.2	*	0.0		48.1	*	0.0		52.1	*	0.0		
21	*	46.2	*	0.0		48.5	*	0.0		50.6	*	0.0		
22		46.1	*	0.0		48.0	*	0.0		51.3	*	0.0		
23	*	46.5	*	0.0	*	0.0	*	0.0	*	50.6	*	0.0		
24		47.0	*	0.0	*	0.0	*	0.0		49.9	*	0.0		
25		47.1	*	0.0	*	0.0	*	0.0	*	49.9	*	0.0		
26		47.0	*	0.0	*	0.0	*	0.0	*	49.9	*	0.0		
27		46.6	*	0.0	*	0.0	*	0.0		49.9	*	0.0		
28	*	46.6	*	0.0	*	0.0	*	0.0		49.8	*	0.0		
29		46.5	*	0.0		48.9	*	0.0	*	49.7	*	0.0		
30		47.0	*	0.0		49.1	*	0.0		49.6	*	0.0		
31		0.0	*	0.0		49.4	*	0.0		0.0		0.0		
MEANS		46.4		0.0		47.8		0.0		50.1		0.0		
OBSVNS.		22		0		22		0		23		0		
MAXIMUM		47.1		0.0		49.4		0.0		52.1		0.0		
MINIMUM		45.4		0.0		46.7		0.0		48.6		0.0		
STD.DEV.		.53		0.00		.78		0.00		1.04		0.00		

CAPE ST JAMES 51 56 18 N 131 00 50 W

	JULY			AUGUST			SEPTEMBER 1977		
DATE	TEMP		SAL	TEMP		SAL	TEMP		SAL
1	49.6	*	0.0	51.8	*	0.0	56.5	*	0.0
2	50.0	*	0.0	51.5	*	0.0	55.5	*	0.0
3	50.5	*	0.0	52.3	*	0.0	* 55.5	*	0.0
4	50.5	*	0.0	52.8	*	0.0	55.4	*	0.0
5	50.0	*	0.0	53.5	*	0.0	56.2	*	0.0
6	52.0	*	0.0	53.6	*	0.0	54.7	*	0.0
7	* 51.4	*	0.0	53.6	*	0.0	53.6	*	0.0
8	50.7	*	0.0	53.8	*	0.0	* 53.7	*	0.0
9	* 50.5	*	0.0	53.6	*	0.0	53.9	*	0.0
10	* 50.3	*	0.0	53.8	*	0.0	56.5	*	0.0
11	50.1	*	0.0	54.3	*	0.0	56.0	*	0.0
12	50.6	*	0.0	54.8	*	0.0	56.0	*	0.0
13	51.0	*	0.0	56.7	*	0.0	* 56.1	*	0.0
14	50.4	*	0.0	57.1	*	0.0	56.2	*	0.0
15	52.0	*	0.0	56.9	*	0.0	55.2	*	0.0
16	51.5	*	0.0	56.4	*	0.0	55.0	*	0.0
17	50.7	*	0.0	55.7	*	0.0	54.9	*	0.0
18	50.5	*	0.0	55.0	*	0.0	* 54.9	*	0.0
19	50.9	*	0.0	54.6	*	0.0	54.8	*	0.0
20	51.6	*	0.0	54.7	*	0.0	55.1	*	0.0
21	51.2	*	0.0	55.3	*	0.0	54.0	*	0.0
22	51.1	*	0.0	55.1	*	0.0	52.5	*	0.0
23	51.5	*	0.0	54.2	*	0.0	53.0	*	0.0
24	53.0	*	0.0	54.8	*	0.0	54.1	*	0.0
25	* 52.5	*	0.0	55.0	*	0.0	52.6	*	0.0
26	52.0	*	0.0	54.0	*	0.0	52.6	*	0.0
27	51.8	*	0.0	54.0	*	0.0	52.8	*	0.0
28	* 52.3	*	0.0	52.5	*	0.0	53.0	*	0.0
29	52.8	*	0.0	53.0	*	0.0	53.0	*	0.0
30	53.1	*	0.0	54.6	*	0.0	51.9	*	0.0
31	52.6	*	0.0	55.4	*	0.0	0.0		0.0
MEANS	51.2		0.0	54.3		0.0	54.4		0.0
OBSVNS.	26		0	31		0	26		0
MAXIMUM	53.1		0.0	57.1		0.0	56.5		0.0
MINIMUM	49.6		0.0	51.5		0.0	51.9		0.0
STD.DEV.	.97		0.00	1.41		0.00	1.42		0.00

CAPE ST JAMES 51 56 18 N 131 00 50 W

	OCTOBER		NOVEMBER		DECEMBER 1977	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	51.7	* 0.0	* 48.2	* 0.0	47.1	* 0.0
2	52.2	* 0.0	47.6	* 0.0	46.9	* 0.0
3	52.2	* 0.0	* 0.0	* 0.0	46.2	* 0.0
4	52.8	* 0.0	* 0.0	* 0.0	46.1	* 0.0
5	53.6	* 0.0	* 0.0	* 0.0	46.2	* 0.0
6	53.3	* 0.0	47.5	* 0.0	46.6	* 0.0
7	52.4	* 0.0	47.3	* 0.0	45.6	* 0.0
8	51.4	* 0.0	47.4	* 0.0	45.0	* 0.0
9	51.6	* 0.0	* 47.9	* 0.0	44.5	* 0.0
10	51.6	* 0.0	48.4	* 0.0	46.0	* 0.0
11	* 50.2	* 0.0	* 0.0	* 0.0	46.0	* 0.0
12	48.7	* 0.0	* 0.0	* 0.0	45.6	* 0.0
13	48.9	* 0.0	* 0.0	* 0.0	45.9	* 0.0
14	50.0	* 0.0	47.3	* 0.0	45.7	* 0.0
15	48.6	* 0.0	47.8	* 0.0	45.5	* 0.0
16	49.0	* 0.0	47.5	* 0.0	45.5	* 0.0
17	48.4	* 0.0	* 0.0	* 0.0	45.4	* 0.0
18	48.7	* 0.0	* 0.0	* 0.0	45.0	* 0.0
19	49.0	* 0.0	* 0.0	* 0.0	45.0	* 0.0
20	49.4	* 0.0	* 0.0	* 0.0	45.4	* 0.0
21	* 48.7	* 0.0	46.9	* 0.0	45.6	* 0.0
22	47.9	* 0.0	46.5	* 0.0	45.9	* 0.0
23	47.5	* 0.0	* 47.0	* 0.0	45.5	* 0.0
24	* 47.2	* 0.0	47.5	* 0.0	45.5	* 0.0
25	* 46.9	* 0.0	47.5	* 0.0	45.4	* 0.0
26	46.5	* 0.0	47.4	* 0.0	45.5	* 0.0
27	* 47.1	* 0.0	47.5	* 0.0	45.5	* 0.0
28	47.8	* 0.0	* 0.0	* 0.0	45.2	* 0.0
29	47.8	* 0.0	* 0.0	* 0.0	45.1	* 0.0
30	* 48.2	* 0.0	* 0.0	* 0.0	45.0	* 0.0
31	48.7	* 0.0	0.0	0.0	45.1	* 0.0
MEANS	50.0	0.0	47.4	0.0	45.6	0.0
OBSVNS.	25	0	14	0	31	0
YRLY.MEANS..					49.2	0.0
MAXIMUM	53.6	0.0	48.4	0.0	47.1	0.0
MINIMUM	46.5	0.0	46.5	0.0	44.5	0.0
STD.DEV.	2.07	0.00	.42	0.00	.57	0.00

EGG ISLAND 51 15 06 N 127 49 53 W

	JANUARY		FEBRUARY		MARCH	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	43.5	30.3	44.9	30.6	45.4	30.6
2	44.5	30.6	44.8	30.3	45.6	30.7
3	44.1	30.8	45.8	30.7	45.6	30.7
4	43.6	30.6	46.5	30.7	45.4	30.7
5	43.4	30.8	46.8	30.7	45.5	30.7
6	44.5	30.8	46.9	30.4	45.5	30.7
7	44.2	30.8	46.7	30.7	45.7	30.7
8	44.1	30.6	46.4	30.7	45.3	30.7
9	44.4	30.6	46.2	31.0	44.9	30.6
10	44.2	30.6	46.3	30.7	44.8	30.6
11	43.7	30.6	45.8	30.7	44.4	30.8
12	43.5	30.6	46.2	30.4	44.3	30.8
13	44.4	30.7	45.8	31.0	44.1	30.8
14	45.0	30.6	46.2	30.7	44.3	30.6
15	45.3	30.7	46.0	30.7	44.6	30.6
16	45.5	30.7	46.6	30.7	44.7	30.6
17	45.6	31.0	46.4	30.7	45.5	30.4
18	45.6	31.2	46.9	30.4	45.7	30.7
19	45.9	31.2	46.9	30.4	45.9	30.7
20	45.7	31.2	46.6	30.7	46.0	31.0
21	45.0	30.8	46.5	30.7	46.2	31.0
22	44.4	30.6	46.4	30.7	46.0	31.0
23	44.2	30.6	45.5	30.7	45.6	31.0
24	44.5	30.8	45.7	30.4	44.9	30.6
25	44.4	30.8	45.6	30.7	44.8	30.8
26	44.1	30.8	45.5	31.0	45.0	30.8
27	43.5	31.1	45.6	31.0	44.6	31.1
28	44.1	30.8	45.4	31.0	44.4	31.1
29	43.4	30.8	0.0	0.0	44.0	30.8
30	43.0	30.4	0.0	0.0	44.4	31.1
31	45.0	30.6	0.0	0.0	45.7	30.2
MEANS	44.4	30.7	46.1	30.7	45.1	30.7
OBSVNS.	31	31	28	28	31	31
MAXIMUM	45.9	31.2	46.9	31.0	46.2	31.1
MINIMUM	43.0	30.3	44.8	30.3	44.0	30.2
STD.DEV.	.77	.22	.58	.20	.63	.20

EGG ISLAND 51 15 06 N 127 49 53 W

	APRIL		MAY		JUNE		1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL	
1	45.6	31.0	49.3	31.4	52.0	32.0	
2	47.3	31.0	48.4	31.1	51.7	31.9	
3	47.5	31.6	48.2	31.4	50.1	32.1	
4	48.2	31.1	48.7	31.4	* 51.0	* 31.8	
5	48.0	31.1	* 49.7	* 31.3	52.0	31.4	
6	48.6	30.8	50.8	31.1	52.8	31.5	
7	49.0	31.2	49.7	31.1	52.9	31.8	
8	48.5	31.1	49.4	30.7	53.1	30.2	
9	48.1	31.1	48.7	30.6	53.6	29.9	
10	47.4	31.4	48.5	30.6	54.4	29.3	
11	* 46.9	* 31.3	51.1	29.9	51.7	31.2	
12	46.4	31.2	50.4	30.0	51.9	31.0	
13	45.3	31.5	50.1	30.0	52.4	31.0	
14	45.5	31.8	49.4	30.7	52.7	30.8	
15	45.9	31.8	49.8	30.8	53.1	31.0	
16	46.5	31.8	50.4	30.8	54.5	29.3	
17	45.6	31.8	50.6	30.8	54.5	30.4	
18	45.9	31.8	50.9	30.0	54.4	29.9	
19	47.0	31.5	51.4	29.9	54.3	29.9	
20	47.2	31.5	51.6	31.0	54.6	30.4	
21	47.8	31.6	52.0	30.8	54.8	31.5	
22	48.1	31.4	51.6	30.7	53.9	31.2	
23	48.0	31.5	51.5	30.7	52.7	31.2	
24	50.7	31.4	51.2	30.7	53.6	31.2	
25	49.5	31.5	51.7	30.2	53.0	31.4	
26	47.8	31.4	51.4	30.2	52.4	31.2	
27	47.9	31.4	49.2	31.4	51.9	31.5	
28	47.8	31.1	50.5	31.1	52.2	31.5	
29	48.5	30.8	52.4	31.0	53.4	31.5	
30	48.9	30.8	51.6	31.4	52.8	31.4	
31	0.0	0.0	51.1	31.4	0.0	0.0	
MEANS	47.5	31.3	50.4	30.8	53.0	31.0	
OBSVNS.	29	29	30	30	29	29	
MAXIMUM	50.7	31.8	52.4	31.4	54.8	32.1	
MINIMUM	45.3	30.8	48.2	29.9	50.1	29.3	
STD.DEV.	1.30	.31	1.20	.49	1.13	.77	

EGG ISLAND 51 15 06 N 127 49 53 W

	JULY		AUGUST		SEPTEMBER 1977	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	52.4	31.2	60.6	27.1	51.2	31.8
2	53.0	30.8	54.6	29.4	51.1	31.8
3	54.4	30.4	57.5	27.8	52.0	31.5
4	57.3	30.3	58.3	29.4	55.1	31.5
5	57.2	28.2	62.4	28.8	53.2	31.5
6	57.2	26.9	58.8	28.8	52.0	31.5
7	57.5	23.8	55.2	29.1	* 52.3	* 31.0
8	58.0	23.1	57.3	28.2	52.7	30.4
9	54.1	27.4	57.7	29.8	51.7	31.0
10	54.5	27.4	56.7	29.7	55.7	30.8
11	55.4	27.3	59.3	29.8	54.4	31.2
12	56.3	27.3	55.4	30.0	54.7	31.2
13	55.2	29.3	58.4	27.2	* 53.9	* 31.0
14	55.4	29.4	55.7	29.8	53.0	30.7
15	55.6	29.1	59.5	30.0	53.5	30.2
16	56.0	29.1	59.2	30.3	52.9	31.0
17	53.7	30.7	59.5	30.3	53.3	31.5
18	55.2	30.6	58.2	29.7	51.8	31.2
19	57.7	28.5	57.7	29.0	50.1	30.6
20	55.8	29.4	57.3	31.4	50.1	31.4
21	58.0	24.6	56.9	28.8	50.0	30.8
22	57.2	28.0	* 56.6	* 28.8	49.0	31.5
23	56.0	27.1	56.3	28.9	49.3	31.2
24	54.7	29.4	* 55.2	* 29.6	50.2	29.0
25	54.7	29.7	54.1	30.4	49.5	31.1
26	58.7	29.3	55.6	30.6	49.5	31.4
27	57.4	26.4	53.8	30.7	49.6	31.6
28	56.3	28.6	53.8	31.4	50.8	31.4
29	56.7	29.7	53.1	31.2	50.3	31.9
30	55.7	28.9	54.2	31.4	50.2	31.6
31	59.6	28.0	52.7	31.4	0.0	0.0
MEANS	56.0	28.4	56.9	29.7	51.7	31.2
OBSVNS.	31	31	29	29	28	28
MAXIMUM	59.6	31.2	62.4	31.4	55.7	31.9
MINIMUM	52.4	23.1	52.7	27.1	49.0	29.0
STD.DEV.	1.67	1.98	2.39	1.19	1.92	.60

EGG ISLAND 51 15 06 N 127 49 53 W

	OCTOBER		NOVEMBER		DECEMBER	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	49.2	31.5	50.9	31.1	45.7	31.0
2	49.0	31.5	49.6	31.1	46.0	30.8
3	50.3	31.1	49.3	31.2	45.5	31.0
4	49.6	31.4	48.0	30.4	* 44.8	* 31.0
5	49.6	31.4	47.1	29.9	44.1	31.0
6	48.9	31.5	47.8	30.8	44.4	30.7
7	50.6	31.4	48.2	30.8	43.5	30.7
8	48.8	31.8	46.4	31.1	44.6	30.7
9	48.9	31.5	47.3	31.4	44.6	30.8
10	49.3	31.5	49.5	31.0	46.0	30.8
11	* 49.3	* 31.5	48.7	30.8	46.0	30.6
12	49.3	31.5	* 48.4	* 31.3	45.7	30.4
13	49.2	31.4	48.0	31.8	45.9	30.8
14	49.2	31.2	48.2	30.8	46.2	30.8
15	50.1	31.2	48.3	31.1	45.9	30.4
16	49.9	31.5	47.1	31.0	45.6	30.3
17	49.4	31.2	45.1	30.8	45.0	30.2
18	49.6	31.2	44.2	29.7	45.3	30.2
19	49.3	31.1	43.7	30.3	45.0	30.0
20	49.3	31.5	44.8	30.8	45.1	30.3
21	49.3	31.6	43.9	30.7	45.1	30.6
22	50.0	31.4	43.5	30.7	45.0	30.2
23	49.4	31.5	45.1	31.1	44.5	30.3
24	48.9	31.4	46.4	30.8	44.4	30.3
25	49.4	31.4	47.1	31.4	44.8	30.4
26	50.1	31.4	46.8	30.8	44.4	29.8
27	51.9	31.6	46.6	30.8	44.8	30.3
28	50.5	31.5	46.6	30.7	44.1	30.6
29	51.9	31.4	46.6	31.2	45.0	30.7
30	51.1	31.4	46.2	30.8	44.2	30.6
31	50.4	31.4	0.0	0.0	43.5	30.3
MEANS	49.7	31.4	46.9	30.9	45.0	30.5
OBSVNS.	30	30	29	29	30	30
YRLY.MEANS..............................					49.4	30.6
MAXIMUM	51.9	31.8	50.9	31.8	46.2	31.0
MINIMUM	48.8	31.1	43.5	29.7	43.5	29.8
STD.DEV.	.62	.15	1.87	.42	.75	.30

PINE ISLAND 50 58 33 N 127 43 35 W

	JANUARY		FEBRUARY		MARCH	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	46.5	31.2	46.0	31.0	46.1	31.0
2	46.5	31.8	46.0	31.0	46.0	31.2
3	46.5	31.5	46.5	31.2	46.1	31.2
4	46.5	31.5	46.5	31.2	46.2	31.0
5	46.5	31.8	46.5	31.0	46.0	30.8
6	46.5	31.5	46.5	31.2	45.8	31.0
7	46.6	31.5	46.0	31.2	45.9	31.2
8	46.0	31.2	46.0	31.5	45.9	31.2
9	46.0	31.5	46.5	31.5	46.0	31.5
10	46.2	31.8	46.5	31.2	46.0	31.2
11	46.3	31.2	46.5	31.2	46.1	31.2
12	46.0	31.2	46.5	31.5	45.8	31.5
13	46.0	31.0	46.5	31.2	46.0	31.5
14	46.4	31.0	46.5	31.2	46.1	31.2
15	46.1	31.0	47.0	31.2	46.2	31.2
16	46.0	31.2	47.0	31.5	45.8	31.5
17	46.0	31.2	47.0	31.2	46.0	31.5
18	46.7	31.0	47.0	31.2	46.0	31.2
19	46.3	31.2	47.0	31.5	46.2	31.0
20	46.5	31.5	47.0	31.2	46.1	31.0
21	46.5	31.2	46.5	31.2	46.0	31.2
22	46.0	31.2	46.5	31.0	46.0	31.2
23	47.0	31.2	46.5	31.2	45.9	31.0
24	46.0	31.2	46.5	31.5	45.8	31.0
25	46.0	31.5	46.5	31.5	46.0	31.2
26	46.1	31.5	46.0	31.5	46.1	31.2
27	46.2	31.5	46.0	31.2	46.1	31.2
28	46.1	31.5	46.0	31.2	46.3	31.0
29	46.0	31.2	0.0	0.0	45.8	31.2
30	46.4	31.2	0.0	0.0	45.8	31.5
31	46.6	31.2	0.0	0.0	45.9	31.5
MEANS	46.3	31.3	46.5	31.3	46.0	31.2
OBSVNS.	31	31	28	28	31	31
MAXIMUM	47.0	31.8	47.0	31.5	46.3	31.5
MINIMUM	46.0	31.0	46.0	31.0	45.8	30.8
STD.DEV.	.27	.23	.35	.17	.14	.19

PINE ISLAND 50 58 33 N 127 43 35 W

	APRIL		MAY		JUNE	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	46.0	31.2	46.9	30.8	47.7	31.2
2	46.0	31.2	46.8	31.0	47.2	31.2
3	46.0	31.2	46.7	31.0	47.3	31.5
4	46.6	31.1	46.5	31.1	48.3	31.5
5	46.6	30.8	46.6	31.4	48.2	31.4
6	46.2	31.1	46.8	31.4	48.6	31.4
7	46.3	31.2	47.3	31.4	48.4	31.4
8	46.3	30.8	47.0	31.4	48.5	31.5
9	45.8	31.4	* 46.8	* 31.4	47.7	31.2
10	46.1	31.1	46.5	31.4	48.1	31.4
11	46.2	31.0	46.2	31.4	48.3	31.4
12	45.9	30.8	46.4	31.2	48.1	31.4
13	45.8	31.0	46.4	31.1	48.2	31.5
14	45.2	31.1	46.7	31.1	48.0	31.4
15	45.7	31.0	47.2	31.1	48.2	31.2
16	45.8	31.0	47.0	31.4	48.3	31.2
17	45.6	31.1	47.0	31.2	49.0	31.4
18	45.7	31.1	47.6	31.2	49.4	31.2
19	46.1	31.1	47.3	31.2	49.5	31.1
20	46.1	31.1	47.3	31.2	49.2	31.0
21	46.1	30.8	47.1	31.4	48.5	31.4
22	46.6	30.8	47.0	31.5	48.2	31.4
23	47.2	31.0	47.5	31.4	48.3	31.2
24	46.8	31.1	47.4	31.4	48.9	31.6
25	46.4	31.2	47.6	31.4	48.3	31.4
26	46.2	31.1	47.2	31.0	48.2	31.4
27	46.3	31.0	46.7	31.1	48.4	31.4
28	46.7	31.2	46.8	31.1	48.4	31.2
29	46.6	31.1	47.3	31.2	48.4	31.5
30	47.2	31.0	47.4	31.2	48.3	31.2
31	0.0	0.0	47.8	31.4	0.0	0.0
MEANS	46.2	31.1	47.0	31.2	48.3	31.3
OBSVNS.	30	30	30	30	30	30
MAXIMUM	47.2	31.4	47.8	31.5	49.5	31.6
MINIMUM	45.2	30.8	46.2	30.8	47.2	31.0
STD.DEV.	.45	.15	.41	.17	.51	.14

PINE ISLAND 50 58 33 N 127 43 35 W

	JULY		AUGUST		SEPTEMBER 1977	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	47.9	31.6	48.6	31.8	50.2	31.2
2	48.1	31.6	48.2	31.5	49.6	31.2
3	48.8	31.6	48.2	31.8	49.2	31.4
4	48.6	31.8	48.7	31.8	49.6	31.4
5	48.7	31.6	49.5	31.9	49.1	31.8
6	48.8	31.6	49.1	31.8	50.2	31.5
7	48.8	31.8	50.2	31.5	50.0	31.5
8	48.6	31.5	50.6	31.5	50.7	32.0
9	49.0	31.6	49.3	31.9	52.0	31.4
10	48.8	31.5	49.1	31.5	52.2	31.2
11	48.1	31.6	50.5	31.5	50.5	31.5
12	47.9	31.4	49.1	31.6	49.6	32.0
13	48.7	31.4	50.2	31.6	49.0	31.6
14	49.0	31.8	50.7	31.5	49.1	31.5
15	49.2	31.5	51.1	31.2	48.6	31.6
16	48.6	31.9	51.0	31.5	49.1	32.4
17	48.2	32.0	50.7	31.4	48.7	31.8
18	48.5	31.8	50.2	31.8	48.6	31.6
19	49.2	31.9	49.6	31.9	48.4	31.2
20	49.0	32.0	49.6	31.9	48.7	31.1
21	48.9	31.8	49.8	31.5	48.7	31.4
22	48.9	31.8	50.2	31.9	48.2	30.8
23	49.8	31.6	49.5	31.5	48.2	31.4
24	49.4	31.8	49.8	31.4	48.4	31.2
25	49.7	31.8	50.0	31.4	48.4	31.2
26	49.3	31.8	49.5	31.1	48.6	32.0
27	49.6	31.6	49.2	31.0	48.3	32.0
28	49.9	31.5	49.0	31.0	48.2	31.4
29	50.0	31.2	48.8	31.4	48.8	31.1
30	49.1	31.2	48.9	31.6	48.6	31.4
31	48.5	31.6	49.6	31.4	0.0	0.0
MEANS	48.9	31.7	49.6	31.6	49.2	31.5
OBSVNS.	31	31	31	31	30	30
MAXIMUM	50.0	32.0	51.1	31.9	52.2	32.4
MINIMUM	47.9	31.2	48.2	31.0	48.2	30.8
STD.DEV.	.56	.20	.78	.26	1.05	.34

PINE ISLAND 50 58 33 N 127 43 35 W

	OCTOBER		NOVEMBER		DECEMBER	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	48.7	31.4	49.5	31.2	46.9	30.8
2	49.3	31.8	48.7	31.1	47.1	30.7
3	50.2	31.8	48.5	31.2	46.2	30.8
4	49.3	32.1	48.4	31.2	46.0	31.5
5	48.6	32.4	48.6	31.6	46.0	30.8
6	48.2	32.1	48.0	31.1	45.1	30.6
7	47.8	31.4	47.8	31.0	44.8	30.4
8	48.2	31.6	47.3	30.8	45.8	30.6
9	48.2	31.4	46.9	31.6	44.6	30.7
10	48.2	31.2	47.8	30.4	45.1	31.1
11	48.4	31.9	47.5	30.6	46.0	30.6
12	48.4	31.4	46.9	30.7	45.3	30.8
13	48.9	31.6	47.6	31.0	45.8	30.6
14	48.6	31.6	47.8	31.1	46.0	30.8
15	48.0	32.7	48.2	31.1	46.0	30.8
16	48.0	31.9	47.6	31.0	46.2	30.8
17	49.1	32.0	47.3	30.6	46.0	30.6
18	50.0	31.5	47.8	31.1	45.7	31.4
19	50.0	31.5	47.1	30.7	45.3	31.8
20	50.0	31.8	46.4	31.0	45.5	31.0
21	50.0	31.8	46.6	30.7	45.7	30.3
22	48.9	31.2	46.4	31.1	44.9	30.8
23	49.8	31.1	45.8	31.4	45.3	30.4
24	50.9	31.9	45.3	30.6	46.0	30.6
25	50.4	31.9	46.6	30.8	46.4	30.7
26	51.3	31.4	46.4	30.7	46.0	30.6
27	50.5	31.4	46.9	30.8	46.2	31.0
28	50.7	31.4	47.1	31.0	46.0	31.0
29	50.2	31.9	47.5	31.0	46.0	30.7
30	49.3	31.2	46.9	31.0	46.0	31.1
31	48.6	31.1	0.0	0.0	45.5	31.0
MEANS	49.2	31.7	47.4	31.0	45.8	30.8
OBSVNS.	31	31	30	30	31	31
YRLY.MEANS....................................					47.5	31.3
MAXIMUM	51.3	32.7	49.5	31.6	47.1	31.8
MINIMUM	47.8	31.1	45.3	30.4	44.6	30.3
STD.DEV.	.99	.38	.91	.27	.56	.32

KAINS ISLAND 50 26 39 N 128 01 47 W

	JANUARY		FEBRUARY		MARCH	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	46.1	29.0	46.3	30.4	47.0	29.4
2	45.8	29.1	46.6	30.4	47.1	29.3
3	45.7	29.4	46.7	30.4	47.3	29.7
4	45.7	29.5	47.3	30.6	47.4	29.9
5	46.9	30.0	47.6	30.6	47.2	30.2
6	47.3	30.2	47.5	30.6	47.1	30.2
7	46.4	30.3	47.6	30.4	46.8	29.1
8	46.7	30.4	48.1	30.6	46.4	29.7
9	47.4	30.4	47.3	30.4	46.5	28.9
10	46.8	30.3	47.5	30.7	46.8	29.3
11	46.8	30.4	47.5	29.9	46.1	29.4
12	46.7	30.4	48.2	30.3	46.6	28.6
13	46.6	30.3	47.7	28.8	46.1	28.5
14	47.3	30.4	47.7	30.2	45.7	28.2
15	47.6	30.4	47.8	29.5	47.0	29.0
16	47.6	30.7	48.0	29.9	47.0	29.1
17	47.6	30.8	47.8	29.9	47.4	29.5
18	47.3	30.2	47.9	28.9	47.8	29.8
19	47.7	30.0	48.7	30.4	47.4	29.8
20	47.6	30.0	48.7	30.4	47.5	29.8
21	47.0	29.8	47.7	30.0	48.2	30.0
22	47.1	30.0	47.5	29.9	47.9	29.8
23	47.2	30.6	47.3	30.3	47.2	28.1
24	47.3	30.4	47.5	30.0	47.6	28.2
25	46.0	30.4	47.3	30.4	47.3	29.0
26	46.3	30.3	47.2	30.0	47.6	29.3
27	46.1	30.4	47.2	29.9	47.7	29.7
28	46.1	30.3	47.1	29.9	47.0	29.0
29	46.4	30.4	0.0	0.0	46.4	28.6
30	45.8	30.4	0.0	0.0	47.2	29.5
31	46.6	30.7	0.0	0.0	48.1	29.5
MEANS	46.8	30.2	47.5	30.1	47.1	29.3
OBSVNS.	31	31	28	28	31	31
MAXIMUM	47.7	30.8	48.7	30.7	48.2	30.2
MINIMUM	45.7	29.0	46.3	28.8	45.7	28.1
STD.DEV.	.64	.43	.54	.47	.59	.58

KAINS ISLAND 50 26 39 N 128 01 47 W

	APRIL		MAY		JUNE	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	47.9	30.8	51.4	30.6	52.0	31.5
2	47.9	31.5	49.1	30.7	51.2	31.8
3	48.6	31.5	50.6	30.0	51.4	31.6
4	48.1	31.2	49.9	30.7	51.3	32.0
5	47.3	31.0	49.6	30.6	52.6	31.1
6	48.1	31.6	49.8	30.7	52.9	31.6
7	48.7	31.6	51.1	30.6	52.2	31.6
8	48.0	31.5	51.2	30.6	52.7	31.9
9	49.1	31.0	51.8	31.0	52.4	31.8
10	49.4	30.7	50.0	30.8	53.0	31.6
11	48.1	30.6	49.6	31.1	52.6	31.8
12	48.0	30.7	49.3	31.0	52.7	31.4
13	48.8	30.2	49.8	31.0	52.3	31.4
14	47.4	30.4	49.1	31.2	52.4	31.2
15	47.4	30.8	51.1	30.7	51.8	31.4
16	47.7	29.9	50.7	31.1	52.5	31.4
17	47.0	30.4	50.4	30.8	52.9	31.5
18	47.3	30.2	50.1	31.4	53.1	31.6
19	47.7	30.0	50.1	31.2	52.0	31.9
20	48.0	30.0	50.0	31.2	52.0	32.0
21	47.8	30.3	50.9	31.5	51.9	32.4
22	48.2	30.6	50.2	31.8	53.2	32.8
23	48.8	29.9	51.6	31.5	52.7	32.7
24	50.1	30.0	51.8	31.5	53.6	32.8
25	49.5	30.2	50.9	31.5	53.2	32.1
26	49.3	30.3	50.4	31.8	53.3	32.8
27	50.3	29.8	50.5	31.9	53.2	32.3
28	49.6	30.2	51.9	31.6	53.2	32.3
29	50.8	29.7	52.2	31.5	54.1	31.9
30	50.0	30.6	51.4	31.2	52.6	32.7
31	0.0	0.0	52.7	31.2	0.0	0.0
MEANS	48.5	30.6	50.6	31.1	52.6	31.9
OBSVNS.	30	30	31	31	30	30
MAXIMUM	50.8	31.6	52.7	31.9	54.1	32.8
MINIMUM	47.0	29.7	49.1	30.0	51.2	31.1
STD.DEV.	1.00	.58	.94	.44	.68	.50

KAINS ISLAND 50 26 39 N 128 01 47 W

	JULY		AUGUST		SEPTEMBER 1977	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	52.7	32.8	57.4	31.8	57.4	32.1
2	52.3	32.9	58.6	31.8	57.4	32.1
3	52.1	32.7	57.2	32.0	57.2	32.0
4	52.2	32.0	55.7	32.4	58.1	32.1
5	54.1	31.9	56.6	32.7	58.8	32.0
6	54.8	32.9	56.8	32.5	59.0	32.1
7	55.2	32.9	57.4	32.8	59.2	32.0
8	55.2	32.5	58.3	32.4	58.9	31.8
9	56.1	32.1	59.6	32.8	58.4	31.5
10	54.1	32.8	61.2	* 33.0	57.8	31.8
11	54.4	32.4	60.0	32.7	56.7	31.9
12	55.3	32.7	57.8	* 33.0	56.4	31.9
13	54.9	32.3	54.5	32.5	55.1	31.9
14	54.6	32.0	54.9	32.9	54.4	31.9
15	55.7	31.5	54.4	** 33.4	54.2	31.9
16	53.8	32.4	55.5	** 33.2	53.9	32.0
17	54.0	32.4	55.6	** 33.0	53.2	32.4
18	54.2	31.8	55.1	** 33.3	53.8	32.3
19	54.8	31.5	56.4	** 33.4	54.3	32.1
20	55.6	32.4	54.8	** 33.2	54.8	31.9
21	55.1	31.5	55.6	** 33.0	54.5	31.6
22	55.0	32.4	54.9	32.3	54.2	31.9
23	55.5	32.4	55.6	32.0	54.0	31.6
24	54.5	32.4	55.1	32.4	54.3	31.8
25	53.9	32.5	55.8	32.7	54.1	31.8
26	54.2	32.8	56.4	32.7	54.4	31.5
27	55.8	32.0	56.1	32.9	54.0	31.8
28	56.1	31.6	56.9	32.5	54.5	31.8
29	55.6	31.8	57.4	32.5	54.2	31.5
30	55.4	31.9	57.2	32.4	54.3	31.8
31	55.3	31.5	58.1	32.4	0.0	0.0
MEANS	54.6	32.2	56.7	32.5	55.7	31.9
OBSVNS.	31	31	31	22	30	30
MAXIMUM	56.1	32.9	61.2	32.9	59.2	32.4
MINIMUM	52.1	31.5	54.4	31.8	53.2	31.5
STD.DEV.	1.10	.46	1.67	.33	1.96	.22

KAINS ISLAND 50 26 39 N 128 01 47 W

	OCTOBER		NOVEMBER		DECEMBER	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	53.6	31.6	51.9	31.0	48.3	28.9
2	54.5	31.5	51.4	30.3	48.4	29.0
3	53.8	31.9	50.4	27.6	47.8	29.4
4	53.6	31.9	50.3	28.1	47.2	28.5
5	53.7	31.9	49.2	26.9	45.7	28.2
6	53.6	31.8	50.9	28.6	46.8	28.6
7	53.4	31.9	50.6	28.9	45.7	29.1
8	53.3	31.5	49.1	27.6	44.8	28.6
9	53.5	31.6	50.3	29.0	46.2	29.5
10	53.6	31.8	50.8	28.6	46.8	29.5
11	53.7	31.5	50.2	28.6	47.9	30.2
12	53.7	31.9	50.0	29.7	47.8	29.1
13	54.0	31.5	49.8	30.0	47.6	28.6
14	52.9	31.4	49.7	29.4	47.3	28.4
15	53.2	31.8	49.5	28.9	47.4	28.9
16	53.3	31.5	49.4	28.6	47.1	28.2
17	53.7	31.5	48.9	28.5	46.1	27.3
18	53.5	31.6	47.0	28.2	46.2	28.2
19	53.3	31.9	46.1	28.2	44.8	28.0
20	52.9	31.4	45.2	28.0	45.9	29.8
21	53.1	31.4	44.9	28.1	46.3	29.3
22	53.4	31.4	45.6	29.0	46.2	29.4
23	53.5	30.6	46.3	29.9	45.8	29.7
24	53.2	31.2	48.2	30.2	45.7	29.7
25	53.1	31.4	48.2	29.7	45.2	29.5
26	52.7	30.8	48.0	29.4	45.6	30.2
27	52.2	29.5	48.2	29.7	45.1	30.3
28	52.2	29.8	48.3	30.0	45.3	29.5
29	52.0	29.4	48.7	30.2	44.9	29.7
30	51.7	29.0	48.0	29.9	46.1	30.3
31	50.9	27.8	0.0	0.0	45.3	29.4
MEANS	53.2	31.2	48.8	29.0	46.4	29.1
OBSVNS.	31	31	30	30	31	31
YRLY.MEANS......................................					50.7	30.7
MAXIMUM	54.5	31.9	51.9	31.0	48.4	30.3
MINIMUM	50.9	27.8	44.9	26.9	44.8	27.3
STD.DEV.	.73	1.00	1.85	.97	1.07	.74

AMPHITRITE POINT 48 55 16 N 125 32 17 W

	JANUARY		FEBRUARY		MARCH	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	46.8	27.8	46.3	29.0	47.7	30.0
2	47.3	29.9	46.1	29.3	46.4	23.3
3	47.0	30.2	45.8	29.8	46.1	26.7
4	46.7	30.0	46.7	29.8	47.2	27.8
5	45.3	29.1	47.0	28.1	47.5	27.4
6	45.7	28.9	47.2	29.7	47.3	27.3
7	45.7	29.3	47.5	29.0	* 47.4	* 28.0
8	45.2	29.7	47.5	29.8	* 47.5	* 28.7
9	45.4	29.3	47.0	29.4	47.6	29.5
10	45.7	29.7	* 0.0	* 0.0	* 47.5	* 29.6
11	46.0	28.6	* 0.0	* 0.0	* 47.3	* 29.8
12	45.9	28.0	* 0.0	* 0.0	47.1	30.0
13	45.3	28.9	47.4	30.6	47.7	29.9
14	46.2	29.3	47.0	29.0	47.4	29.5
15	47.0	30.4	47.6	30.4	48.1	30.3
16	* 47.2	* 30.4	47.7	29.4	47.7	29.9
17	* 47.5	* 30.3	47.9	28.9	48.0	30.0
18	47.8	30.2	48.9	29.0	48.4	30.6
19	47.2	30.2	48.6	29.9	48.3	30.8
20	47.2	28.9	* 0.0	* 0.0	48.0	29.5
21	46.8	29.0	* 0.0	* 0.0	47.8	27.7
22	46.0	28.6	* 0.0	* 0.0	47.5	24.8
23	45.3	28.9	47.7	29.5	46.8	27.3
24	45.0	29.0	46.5	29.1	47.1	29.1
25	44.8	29.1	* 46.2	* 29.4	47.4	28.9
26	44.9	29.5	45.9	29.8	47.6	28.4
27	44.8	29.3	47.0	26.9	47.2	27.8
28	45.6	29.7	47.2	28.1	47.4	30.0
29	45.0	29.5	0.0	0.0	47.3	30.0
30	45.4	29.7	0.0	0.0	46.9	30.3
31	46.0	25.1	0.0	0.0	47.8	30.7
MEANS	46.0	29.2	47.2	29.3	47.5	28.8
OBSVNS.	29	29	21	21	27	27
MAXIMUM	47.8	30.4	48.9	30.6	48.4	30.8
MINIMUM	44.8	25.1	45.8	26.9	46.1	23.3
STD.DEV.	.86	1.00	.80	.83	.53	1.83

AMPHITRITE POINT 48 55 16 N 125 32 17 W

	APRIL		MAY		JUNE	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	48.3	30.7	52.0	29.4	51.6	29.9
2	48.8	30.0	51.1	28.2	52.1	30.8
3	49.4	30.2	49.3	29.1	53.4	28.1
4	49.6	29.9	50.7	30.6	53.5	27.7
5	50.1	30.3	51.1	31.0	55.8	28.5
6	49.5	29.8	51.8	31.0	53.4	29.7
7	49.8	29.4	51.7	30.0	52.6	30.6
8	* 49.8	* 29.5	51.9	30.4	51.7	31.5
9	* 49.9	* 29.7	51.4	31.1	52.8	31.4
10	49.9	29.9	50.6	31.2	53.7	31.0
11	50.2	30.4	49.5	31.6	53.1	30.4
12	49.1	28.5	49.8	31.2	54.3	30.8
13	48.3	28.0	51.2	29.8	54.0	31.2
14	49.0	28.9	50.9	29.4	55.2	30.7
15	47.3	23.8	51.0	30.2	54.8	31.0
16	47.5	24.6	52.6	29.9	54.4	31.0
17	48.3	29.3	51.8	30.2	53.8	31.1
18	48.6	30.0	52.4	30.7	52.6	31.8
19	49.1	30.4	52.1	31.4	51.8	31.4
20	49.4	30.3	51.6	29.5	53.1	30.7
21	49.0	28.8	52.3	28.8	52.6	28.5
22	49.6	24.6	51.9	30.6	54.3	30.3
23	50.2	28.1	51.1	31.1	53.6	31.1
24	49.8	29.8	52.4	31.8	52.1	29.8
25	49.6	29.4	50.9	30.6	52.3	30.0
26	49.8	29.9	* 50.5	* 27.5	53.9	31.6
27	49.4	29.9	50.1	24.4	52.8	31.5
28	49.3	30.2	50.3	29.5	* 53.4	* 31.8
29	51.6	29.1	50.6	30.2	54.1	32.1
30	51.4	29.5	51.4	29.9	53.9	31.5
31	0.0	0.0	50.9	28.1	0.0	0.0
MEANS	49.4	29.1	51.2	30.0	53.4	30.5
OBSVNS.	28	28	30	30	29	29
MAXIMUM	51.6	30.7	52.6	31.8	55.8	32.1
MINIMUM	47.3	23.8	49.3	24.4	51.6	27.7
STD.DEV.	.95	1.81	.86	1.42	1.06	1.13

AMPHITRITE POINT 48 55 16 N 125 32 17 W

	JULY		AUGUST		SEPTEMBER 1977	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	52.4	30.0	55.7	31.6	58.0	32.0
2	53.3	32.1	59.6	31.4	56.8	30.8
3	52.3	31.8	59.8	31.2	56.9	31.1
4	54.2	31.5	58.3	31.2	57.3	31.6
5	54.4	31.5	57.4	31.5	57.6	32.1
6	54.9	31.9	58.3	31.5	56.7	31.8
7	54.1	31.4	57.9	31.5	56.4	31.6
8	53.8	31.6	57.9	31.5	55.8	31.1
9	52.5	32.4	56.8	31.6	55.1	30.7
10	51.3	31.9	55.3	31.4	56.3	31.6
11	50.9	31.2	58.8	31.6	56.5	31.0
12	52.1	31.4	58.0	31.5	57.2	30.7
13	53.2	31.6	58.7	31.6	57.4	31.0
14	53.6	31.9	58.4	31.6	57.8	30.6
15	53.9	31.8	58.5	31.5	56.9	30.6
16	52.1	28.9	58.9	31.8	58.5	31.0
17	51.9	31.5	59.3	31.4	57.1	30.3
18	52.8	31.6	58.1	30.8	56.7	29.4
19	53.6	31.5	58.8	31.4	56.5	28.6
20	54.3	32.0	58.4	31.6	55.9	29.4
21	52.9	31.8	57.8	31.6	54.0	30.3
22	54.2	31.5	56.1	31.8	53.8	30.4
23	54.9	31.5	57.6	30.4	53.6	28.8
24	55.1	31.8	* 57.0	* 29.3	53.0	29.8
25	53.6	32.4	56.4	28.2	53.2	28.5
26	51.9	32.0	56.2	30.0	56.0	30.2
27	52.0	32.0	57.1	31.4	56.2	30.6
28	53.0	31.6	56.9	31.2	56.8	31.1
29	55.1	31.4	57.4	30.6	55.9	30.7
30	56.1	31.4	58.6	31.9	54.2	30.2
31	55.7	31.6	59.1	32.3	0.0	0.0
MEANS	53.4	31.6	57.9	31.3	56.1	30.6
OBSVNS.	31	31	30	30	30	30
MAXIMUM	56.1	32.4	59.8	32.3	58.5	32.1
MINIMUM	50.9	28.9	55.3	28.2	53.0	28.5
STD.DEV.	1.31	.65	1.15	.73	1.46	.94

AMPHITRITE POINT 48 55 16 N 125 32 17 W

	OCTOBER		NOVEMBER		DECEMBER	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	55.9	31.5	52.0	28.9	48.4	25.8
2	55.1	31.1	52.2	30.3	49.2	27.4
3	55.8	31.2	50.8	30.0	49.8	30.6
4	55.6	31.0	50.2	27.3	* 48.6	* 29.6
5	55.3	30.6	50.3	27.1	47.3	28.6
6	53.8	30.4	49.6	26.8	47.0	25.5
7	54.5	31.1	50.0	30.0	49.5	31.1
8	54.6	30.3	49.8	29.8	46.4	29.8
9	53.6	31.1	49.3	28.5	44.2	28.4
10	54.3	30.8	50.9	29.3	46.8	20.4
11	54.6	31.0	51.2	28.0	47.9	30.4
12	53.9	30.3	* 51.7	* 29.1	48.4	30.3
13	54.5	30.6	52.3	30.3	46.2	28.6
14	53.8	30.4	* 52.3	* 30.5	48.9	27.6
15	53.5	30.8	52.2	30.7	49.0	28.1
16	53.0	31.0	51.4	30.0	48.0	27.1
17	52.7	31.1	48.2	28.8	47.2	25.5
18	52.5	30.6	46.2	25.6	46.2	24.6
19	52.4	30.7	41.6	26.4	45.7	24.3
20	51.5	30.6	44.6	24.4	47.4	26.8
21	52.7	27.2	42.3	25.0	* 47.4	* 27.3
22	51.9	29.8	45.0	28.0	47.3	27.8
23	50.4	30.8	45.7	28.1	46.0	26.5
24	51.4	29.0	47.8	29.0	46.0	27.2
25	* 51.8	* 29.6	47.6	28.0	45.3	26.7
26	52.3	30.2	49.2	29.9	45.0	26.1
27	52.2	30.6	47.0	25.9	44.7	26.0
28	* 52.5	* 30.7	49.2	29.3	44.7	26.4
29	52.8	30.8	49.6	29.8	46.9	26.5
30	52.8	31.1	49.0	28.4	45.9	26.8
31	51.8	28.2	0.0	0.0	45.3	26.8
MEANS	53.4	30.5	48.8	28.3	47.0	27.2
OBSVNS.	29	29	28	28	29	29
YRLY.MEANS......................................					51.1	29.7
MAXIMUM	55.9	31.5	52.3	30.7	49.8	31.1
MINIMUM	50.4	27.2	41.6	24.4	44.2	20.4
STD.DEV.	1.44	.92	2.88	1.73	1.56	2.19

SHERINGHAM POINT 48 22 40 N 123 55 10 W

	JANUARY		FEBRUARY		MARCH	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	46.8	* 0.0	45.2	* 0.0	45.6	* 0.0
2	45.9	* 0.0	45.2	* 0.0	46.5	* 0.0
3	46.0	* 0.0	45.8	* 0.0	45.9	* 0.0
4	45.7	* 0.0	45.1	* 0.0	46.4	* 0.0
5	45.2	* 0.0	45.6	* 0.0	45.9	* 0.0
6	45.4	* 0.0	45.8	* 0.0	46.8	* 0.0
7	44.2	* 0.0	46.2	* 0.0	46.1	* 0.0
8	45.2	* 0.0	45.3	* 0.0	46.8	* 0.0
9	45.0	* 0.0	46.5	* 0.0	46.1	* 0.0
10	45.9	* 0.0	45.2	* 0.0	46.8	* 0.0
11	45.0	* 0.0	45.5	* 0.0	46.2	* 0.0
12	45.8	* 0.0	45.4	* 0.0	46.5	* 0.0
13	46.0	* 0.0	46.2	* 0.0	46.4	* 0.0
14	45.9	* 0.0	46.1	* 0.0	47.0	* 0.0
15	45.8	* 0.0	47.0	* 0.0	46.8	* 0.0
16	* 45.9	* 0.0	46.2	* 0.0	46.0	* 0.0
17	46.0	* 0.0	46.8	* 0.0	46.4	* 0.0
18	46.2	* 0.0	46.3	* 0.0	46.7	* 0.0
19	45.8	* 0.0	46.8	* 0.0	46.5	* 0.0
20	46.2	* 0.0	45.8	* 0.0	46.4	* 0.0
21	46.1	* 0.0	* 45.8	* 0.0	47.2	* 0.0
22	45.9	* 0.0	45.8	* 0.0	47.0	* 0.0
23	46.0	* 0.0	45.7	* 0.0	47.0	* 0.0
24	45.8	* 0.0	45.9	* 0.0	47.1	* 0.0
25	45.5	* 0.0	45.5	* 0.0	47.0	* 0.0
26	45.5	* 0.0	45.7	* 0.0	47.2	* 0.0
27	45.4	* 0.0	47.6	* 0.0	46.5	* 0.0
28	45.2	* 0.0	46.6	* 0.0	46.5	* 0.0
29	45.2	* 0.0	0.0	0.0	47.4	* 0.0
30	45.2	* 0.0	0.0	0.0	46.7	* 0.0
31	45.3	* 0.0	0.0	0.0	47.3	* 0.0
MEANS	45.6	0.0	46.0	0.0	46.6	0.0
OBSVNS.	30	0	27	0	31	0
MAXIMUM	46.8	0.0	47.6	0.0	47.4	0.0
MINIMUM	44.2	0.0	45.1	0.0	45.6	0.0
STD.DEV.	.50	0.00	.63	0.00	.45	0.00

SHERINGHAM POINT 48 22 40 N 123 55 10 W

	APRIL		MAY		JUNE	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	46.7	* 0.0	47.9	* 0.0	48.9	* 0.0
2	* 46.7	* 0.0	47.9	* 0.0	49.0	* 0.0
3	46.8	* 0.0	48.1	* 0.0	49.9	* 0.0
4	47.0	* 0.0	47.5	* 0.0	49.8	* 0.0
5	47.5	* 0.0	48.3	* 0.0	49.6	* 0.0
6	47.1	* 0.0	47.6	* 0.0	49.9	* 0.0
7	47.0	* 0.0	48.2	* 0.0	49.1	* 0.0
8	47.2	* 0.0	47.7	* 0.0	49.7	* 0.0
9	47.1	* 0.0	48.0	* 0.0	49.2	* 0.0
10	47.1	* 0.0	47.8	* 0.0	49.6	* 0.0
11	47.2	* 0.0	48.1	* 0.0	49.9	* 0.0
12	47.4	* 0.0	48.0	* 0.0	49.9	* 0.0
13	47.2	* 0.0	48.2	* 0.0	49.6	* 0.0
14	47.5	* 0.0	48.3	* 0.0	49.7	* 0.0
15	47.2	* 0.0	48.3	* 0.0	49.4	* 0.0
16	47.4	* 0.0	47.9	* 0.0	50.0	* 0.0
17	47.2	* 0.0	48.4	* 0.0	49.5	* 0.0
18	47.6	* 0.0	49.3	* 0.0	49.8	* 0.0
19	47.4	* 0.0	48.4	* 0.0	49.9	* 0.0
20	47.8	* 0.0	49.0	* 0.0	50.2	* 0.0
21	47.6	* 0.0	49.1	* 0.0	50.6	* 0.0
22	47.8	* 0.0	49.3	* 0.0	50.2	* 0.0
23	47.8	* 0.0	48.5	* 0.0	50.8	* 0.0
24	47.9	* 0.0	48.8	* 0.0	50.3	* 0.0
25	47.8	* 0.0	* 48.9	* 0.0	50.3	* 0.0
26	48.0	* 0.0	49.1	* 0.0	50.4	* 0.0
27	47.9	* 0.0	48.6	* 0.0	50.7	* 0.0
28	47.7	* 0.0	49.2	* 0.0	50.7	* 0.0
29	47.6	* 0.0	48.6	* 0.0	50.5	* 0.0
30	47.9	* 0.0	49.4	* 0.0	50.8	* 0.0
31	0.0	0.0	48.6	* 0.0	0.0	0.0
MEANS	47.4	0.0	48.4	0.0	49.9	0.0
OBSVNS.	29	0	30	0	30	0
MAXIMUM	48.0	0.0	49.4	0.0	50.8	0.0
MINIMUM	46.7	0.0	47.5	0.0	48.9	0.0
STD.DEV.	.36	0.00	.55	0.00	.53	0.00

SHERINGHAM POINT 48 22 40 N 123 55 10 W

	JULY			AUGUST			SEPTEMBER 1977		
DATE	TEMP		SAL	TEMP		SAL	TEMP		SAL
1	49.5	*	0.0	51.8	*	0.0	52.2	*	0.0
2	50.6	*	0.0	51.8	*	0.0	53.7	*	0.0
3	48.8	*	0.0	52.8	*	0.0	52.5	*	0.0
4	51.2	*	0.0	52.7	*	0.0	52.2	*	0.0
5	49.8	*	0.0	52.7	*	0.0	51.9	*	0.0
6	51.5	*	0.0	52.1	*	0.0	52.4	*	0.0
7	49.3	*	0.0	52.3	*	0.0	52.5	*	0.0
8	51.4	*	0.0	54.1	*	0.0	52.3	*	0.0
9	50.2	*	0.0	54.3	*	0.0	52.5	*	0.0
10	51.6	*	0.0	53.6	*	0.0	52.1	*	0.0
11	52.3	*	0.0	53.7	*	0.0	52.1	*	0.0
12	51.4	*	0.0	54.2	*	0.0	52.4	*	0.0
13	52.3	*	0.0	53.3	*	0.0	52.0	*	0.0
14	51.8	*	0.0	52.9	*	0.0	52.1	*	0.0
15	52.3	*	0.0	53.2	*	0.0	52.2	*	0.0
16	51.6	*	0.0	51.8	*	0.0	52.0	*	0.0
17	50.6	*	0.0	52.1	*	0.0	51.4	*	0.0
18	51.2	*	0.0	52.3	*	0.0	50.8	*	0.0
19	51.5	*	0.0	51.1	*	0.0	50.5	*	0.0
20	51.2	*	0.0	50.9	*	0.0	50.7	*	0.0
21	51.1	*	0.0	50.3	*	0.0	50.4	*	0.0
22	51.3	*	0.0	50.4	*	0.0	50.7	*	0.0
23	51.4	*	0.0	51.8	*	0.0	50.3	*	0.0
24	51.2	*	0.0	50.9	*	0.0	50.6	*	0.0
25	50.8	*	0.0	51.7	*	0.0	50.1	*	0.0
26	51.4	*	0.0	51.3	*	0.0	50.6	*	0.0
27	52.2	*	0.0	50.9	*	0.0	50.4	*	0.0
28	51.5	*	0.0	51.8	*	0.0	50.2	*	0.0
29	51.5	*	0.0	52.9	*	0.0	49.8	*	0.0
30	51.8	*	0.0	52.5	*	0.0	49.7	*	0.0
31	51.1	*	0.0	52.1	*	0.0	0.0		0.0
MEANS	51.1		0.0	52.3		0.0	51.4		0.0
OBSVNS.	31		0	31		0	30		0
MAXIMUM	52.3		0.0	54.3		0.0	53.7		0.0
MINIMUM	48.8		0.0	50.3		0.0	49.7		0.0
STD.DEV.	.86		0.00	1.08		0.00	1.03		0.00

SHERINGHAM POINT   48 22 40 N   123 55 10 W

DATE	OCTOBER TEMP		OCTOBER SAL	NOVEMBER TEMP		NOVEMBER SAL	DECEMBER 1977 TEMP		DECEMBER 1977 SAL
1	49.8	*	0.0	48.9	*	0.0	46.7	*	0.0
2	49.8	*	0.0	49.3	*	0.0	47.3	*	0.0
3	50.2	*	0.0	48.7	*	0.0	46.4	*	0.0
4	49.4	*	0.0	49.1	*	0.0	47.6	*	0.0
5	50.1	*	0.0	48.9	*	0.0	46.5	*	0.0
6	49.4	*	0.0	48.7	*	0.0	46.6	*	0.0
7	49.8	*	0.0	48.7	*	0.0	46.3	*	0.0
8	49.2	*	0.0	48.8	*	0.0	46.5	*	0.0
9	49.6	*	0.0	48.6	*	0.0	46.1	*	0.0
10	49.4	*	0.0	48.5	*	0.0	46.4	*	0.0
11	50.3	*	0.0	48.2	*	0.0	46.2	*	0.0
12	49.8	*	0.0	48.1	*	0.0	46.5	*	0.0
13	50.2	*	0.0	48.3	*	0.0	46.1	*	0.0
14	49.5	*	0.0	48.3	*	0.0	46.8	*	0.0
15	49.0	*	0.0	47.9	*	0.0	46.0	*	0.0
16	49.3	*	0.0	48.4	*	0.0	46.8	*	0.0
17	48.8	*	0.0	48.1	*	0.0	46.2	*	0.0
18	49.7	*	0.0	48.2	*	0.0	46.4	*	0.0
19	49.3	*	0.0	47.7	*	0.0	46.1	*	0.0
20	49.2	*	0.0	47.5	*	0.0	45.6	*	0.0
21	49.0	*	0.0	47.4	*	0.0	46.1	*	0.0
22	49.4	*	0.0	47.1	*	0.0	46.0	*	0.0
23	49.1	*	0.0	46.7	*	0.0	45.4	*	0.0
24	49.1	*	0.0	47.0	*	0.0	45.9	*	0.0
25	48.5	*	0.0	47.2	*	0.0	45.6	*	0.0
26	49.1	*	0.0	47.3	*	0.0	46.0	*	0.0
27	48.6	*	0.0	47.2	*	0.0	45.3	*	0.0
28	49.0	*	0.0	47.1	*	0.0	46.1	*	0.0
29	49.2	*	0.0	46.5	*	0.0	45.6	*	0.0
30	48.9	*	0.0	47.0	*	0.0	45.6	*	0.0
31	49.0	*	0.0	0.0		0.0	44.9	*	0.0
MEANS	49.4		0.0	48.0		0.0	46.2		0.0
OBSVNS.	31		0	30		0	31		0
YRLY.MEANS....................................							48.6		0.0
MAXIMUM	50.3		0.0	49.3		0.0	47.6		0.0
MINIMUM	48.5		0.0	46.5		0.0	44.9		0.0
STD.DEV.	.46		0.00	.78		0.00	.56		0.00

RACE ROCKS 48 17 57 N 123 31 48 W

	JANUARY		FEBRUARY		MARCH	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	46.2	31.4	45.6	30.8	46.5	31.0
2	46.0	31.5	45.6	31.0	46.4	30.8
3	45.9	31.1	45.7	31.1	46.7	30.7
4	45.7	31.0	46.2	31.4	46.6	30.8
5	45.6	31.0	46.1	31.4	46.6	31.1
6	45.7	31.1	46.0	31.2	46.8	31.0
7	45.7	31.0	46.1	31.4	46.4	31.0
8	45.6	31.1	46.3	31.5	46.5	31.2
9	45.5	31.1	46.4	31.5	46.6	31.4
10	45.6	31.2	46.5	31.4	46.6	31.6
11	45.7	31.4	46.1	31.5	46.3	31.1
12	45.5	31.8	45.7	31.2	46.1	30.8
13	45.6	31.4	45.9	31.5	46.6	31.1
14	45.5	31.0	46.2	31.5	46.6	30.8
15	45.7	31.0	46.5	31.6	46.5	30.6
16	45.8	31.1	47.0	31.8	46.6	30.6
17	46.0	31.2	46.7	31.4	46.5	30.8
18	46.3	31.4	46.8	31.5	46.7	30.7
19	46.3	31.4	47.0	31.5	46.5	30.8
20	46.1	31.4	46.7	31.8	46.3	31.1
21	46.4	31.5	* 46.8	* 31.8	46.5	31.2
22	46.2	31.6	46.9	31.8	47.0	30.8
23	45.8	31.4	47.0	31.9	47.0	31.2
24	46.0	31.5	46.9	31.6	46.7	30.8
25	46.0	31.6	46.5	31.2	46.3	30.7
26	45.4	31.2	46.2	31.0	46.5	31.0
27	45.1	31.1	46.2	31.0	46.3	30.8
28	45.0	30.6	46.4	31.0	46.6	30.6
29	45.0	30.8	0.0	0.0	46.5	30.4
30	45.1	30.6	0.0	0.0	46.7	30.0
31	45.3	30.6	0.0	0.0	46.8	30.3
MEANS	45.7	31.2	46.3	31.4	46.6	30.9
OBSVNS.	31	31	27	27	31	31
MAXIMUM	46.4	31.8	47.0	31.9	47.0	31.6
MINIMUM	45.0	30.6	45.6	30.8	46.1	30.0
STD.DEV.	.38	.30	.44	.28	.20	.32

RACE ROCKS 48 17 57 N 123 31 48 W

	APRIL		MAY		JUNE 1977	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	46.8	31.0	48.0	31.5	48.5	31.5
2	46.7	31.0	47.7	31.4	48.6	31.6
3	46.8	31.1	47.5	31.5	48.5	31.6
4	46.9	31.2	46.9	31.5	48.4	31.5
5	47.1	31.5	46.5	32.0	48.2	31.6
6	47.0	31.4	46.9	31.5	48.5	31.6
7	47.2	31.8	47.2	31.5	48.7	31.6
8	46.3	31.8	47.7	31.2	48.9	31.5
9	46.5	31.6	47.4	31.2	49.3	31.6
10	46.6	31.8	47.3	31.2	49.2	31.8
11	46.8	31.5	47.0	31.1	49.5	31.8
12	46.7	31.5	47.3	31.2	50.3	31.1
13	46.8	31.8	47.6	31.2	50.6	30.4
14	46.4	31.6	47.7	31.5	50.5	31.0
15	46.6	31.5	48.1	31.8	50.6	30.7
16	46.8	31.5	48.0	31.2	50.4	30.6
17	46.7	31.6	48.1	31.4	50.5	30.7
18	46.9	31.9	48.3	31.6	50.2	30.8
19	46.7	31.9	48.2	31.4	50.0	30.7
20	46.8	31.6	48.1	31.5	49.9	31.0
21	47.0	31.9	48.3	31.5	49.6	31.1
22	47.2	31.8	48.4	31.6	49.5	31.1
23	47.4	31.6	48.3	31.8	49.7	31.2
24	47.6	31.8	48.4	31.6	49.6	30.8
25	47.5	31.5	48.5	31.8	49.7	31.2
26	47.7	31.8	48.4	31.5	50.0	31.2
27	47.8	31.6	48.4	31.5	50.2	31.4
28	47.9	31.6	48.5	31.5	50.4	31.5
29	48.1	31.6	48.5	31.4	50.3	31.4
30	48.0	31.6	48.6	31.4	50.2	31.6
31	0.0	0.0	48.5	31.2	0.0	0.0
MEANS	47.0	31.6	47.9	31.5	49.6	31.2
OBSVNS.	30	30	31	31	30	30
MAXIMUM	48.1	31.9	48.6	32.0	50.6	31.8
MINIMUM	46.3	31.0	46.5	31.1	48.2	30.4
STD.DEV.	.49	.25	.58	.21	.77	.39

RACE ROCKS 48 17 57 N 123 31 48 W

	JULY		AUGUST		SEPTEMBER 1977	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	49.7	31.9	50.1	31.5	50.0	31.9
2	49.3	32.3	50.1	31.6	50.1	31.8
3	49.3	32.1	50.2	31.4	50.0	31.8
4	49.4	31.9	50.4	31.1	50.1	31.6
5	49.6	31.9	50.6	30.8	50.8	30.7
6	49.9	31.8	51.4	30.6	51.0	31.0
7	50.1	31.8	52.3	30.4	51.0	30.8
8	50.0	31.9	53.2	30.3	51.2	30.7
9	50.4	31.8	53.7	30.7	51.3	30.7
10	50.7	31.5	54.0	30.6	51.3	30.6
11	50.6	31.6	54.2	30.4	51.6	30.8
12	50.8	31.4	54.4	30.4	51.7	30.8
13	51.0	31.4	54.0	30.6	51.6	31.0
14	50.5	31.4	53.2	30.4	51.7	31.1
15	49.7	31.6	52.0	30.3	51.5	30.8
16	49.5	31.6	52.1	30.3	51.0	30.8
17	49.3	31.9	51.9	30.6	50.0	31.0
18	49.5	31.6	51.8	30.6	50.2	30.8
19	49.8	31.5	52.0	30.8	50.5	31.1
20	50.2	31.1	51.9	30.7	50.4	31.2
21	50.2	31.2	51.7	30.8	50.5	31.4
22	50.0	31.1	51.8	31.1	50.4	31.8
23	49.9	30.8	51.4	31.0	50.1	31.5
24	49.9	31.0	51.2	31.2	50.1	31.9
25	50.0	31.1	50.7	31.4	50.0	31.9
26	49.8	31.2	50.4	31.2	49.8	31.9
27	49.7	31.2	50.0	31.4	49.9	32.0
28	49.8	31.4	49.8	31.8	49.7	31.9
29	50.1	31.5	49.7	32.0	49.4	32.0
30	50.0	31.6	49.8	31.9	49.5	31.9
31	50.2	31.5	49.6	32.1	0.0	0.0
MEANS	50.0	31.5	51.6	31.0	50.5	31.3
OBSVNS.	31	31	31	31	30	30
MAXIMUM	51.0	32.3	54.4	32.1	51.7	32.0
MINIMUM	49.3	30.8	49.6	30.3	49.4	30.6
STD.DEV.	.44	.35	1.47	.54	.70	.51

RACE ROCKS 48 17 57 N 123 31 48 W

	OCTOBER		NOVEMBER		DECEMBER	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	49.4	31.0	48.4	31.9	46.9	31.2
2	49.2	31.1	48.3	31.8	46.8	31.4
3	49.1	31.5	48.4	31.9	46.9	31.2
4	49.1	31.5	48.3	31.8	47.0	31.4
5	49.3	31.4	48.2	31.9	46.8	31.1
6	49.2	31.1	48.2	31.6	46.8	31.4
7	49.4	31.4	48.1	31.8	46.7	31.5
8	49.2	31.2	48.1	31.6	46.7	31.4
9	49.0	31.5	48.0	31.5	46.5	31.5
10	49.1	31.5	47.9	31.6	46.3	31.5
11	49.2	31.4	47.8	31.5	46.4	31.2
12	49.0	31.2	47.8	31.6	46.7	31.1
13	49.1	31.5	47.7	31.5	46.7	30.8
14	49.0	31.8	47.7	31.4	46.5	31.0
15	48.9	31.5	47.6	31.5	46.3	30.6
16	48.8	31.8	47.5	31.4	46.5	30.4
17	48.7	31.9	47.5	31.5	46.8	30.3
18	48.5	32.1	47.4	31.5	46.6	30.2
19	48.4	32.3	47.4	31.5	46.7	30.3
20	48.5	32.1	47.2	31.5	46.6	30.3
21	48.5	32.1	46.5	31.2	46.5	30.4
22	48.6	31.9	46.7	31.4	46.3	30.3
23	48.5	31.9	46.8	31.5	46.3	30.4
24	48.5	32.0	46.9	31.4	46.0	30.4
25	48.2	31.8	46.8	31.4	45.8	30.3
26	48.1	31.9	46.9	31.2	45.6	30.0
27	48.1	32.0	46.9	31.1	45.6	30.2
28	48.2	31.8	46.7	31.2	45.4	30.3
29	48.0	31.9	46.8	31.5	45.2	30.0
30	47.9	32.0	46.8	31.4	45.3	30.0
31	47.7	31.8	0.0	0.0	45.2	30.4
MEANS	48.7	31.7	47.5	31.5	46.3	30.7
OBSVNS.	31	31	30	30	31	31
YRLY.MEANS..					48.2	31.3
MAXIMUM	49.4	32.3	48.4	31.9	47.0	31.5
MINIMUM	47.7	31.0	46.5	31.1	45.2	30.0
STD.DEV.	.48	.34	.61	.21	.54	.53

CAPE MUDGE 49 59 56 N 125 11 38 W

	JANUARY		FEBRUARY		MARCH	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	46.2	28.5	46.5	29.5	47.7	28.9
2	45.6	28.6	46.6	29.4	* 48.4	* 28.9
3	46.2	29.0	46.4	29.3	49.1	28.9
4	46.5	29.0	* 46.4	* 29.3	* 0.0	* 0.0
5	46.5	29.0	46.3	29.3	* 0.0	* 0.0
6	46.0	29.3	* 46.0	* 29.2	* 0.0	* 0.0
7	46.2	29.3	45.6	29.1	* 0.0	* 0.0
8	43.2	28.8	45.7	29.0	45.7	28.9
9	43.0	28.9	45.6	29.3	* 45.2	* 28.9
10	43.8	28.6	* 45.8	* 29.2	44.7	28.8
11	45.3	28.9	46.0	29.1	* 45.0	* 28.8
12	44.2	28.9	* 46.5	* 29.2	45.3	28.9
13	45.3	28.9	47.0	29.3	46.6	28.8
14	44.9	28.9	* 47.3	* 29.3	46.2	28.9
15	45.7	28.9	47.6	29.3	47.7	28.9
16	* 46.1	* 29.0	48.2	29.7	46.8	29.0
17	* 46.5	* 29.1	48.2	29.3	48.8	29.0
18	47.0	29.1	47.4	29.0	48.5	29.0
19	46.8	29.1	46.8	29.5	48.2	28.9
20	46.3	29.3	* 46.5	* 29.4	* 48.1	* 29.0
21	46.2	29.1	* 46.2	* 29.2	48.0	29.1
22	* 45.4	* 29.0	45.8	29.1	45.6	29.1
23	44.6	28.9	45.1	29.0	45.3	29.1
24	44.7	29.1	44.3	29.0	45.8	29.3
25	44.0	29.0	* 44.5	* 29.0	46.0	29.1
26	44.3	29.0	44.8	28.9	45.6	28.9
27	44.3	28.8	45.2	28.9	45.2	29.3
28	* 44.8	* 28.9	46.2	28.9	45.5	29.1
29	45.3	29.0	0.0	0.0	46.0	29.0
30	45.0	29.1	0.0	0.0	47.1	29.3
31	46.1	29.1	0.0	0.0	51.0	29.1
MEANS	45.3	29.0	46.3	29.2	46.8	29.0
OBSVNS.	27	27	20	20	23	23
MAXIMUM	47.0	29.3	48.2	29.7	51.0	29.3
MINIMUM	43.0	28.5	44.3	28.9	44.7	28.8
STD.DEV.	1.10	.20	1.07	.23	1.58	.15

CAPE MUCGE 49 59 56 N 125 11 38 W

	APRIL		MAY		JUNE	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	51.7	29.3	* 0.0	* 0.0	54.3	29.0
2	51.8	29.5	* 0.0	* 0.0	54.0	28.6
3	50.6	29.4	* 0.0	* 0.0	* 54.5	* 28.6
4	49.3	29.3	* 0.0	* 0.0	55.0	28.6
5	49.8	29.5	* 0.0	* 0.0	51.0	27.3
6	45.7	29.4	* 0.0	* 0.0	52.0	28.8
7	46.5	29.4	* 0.0	* 0.0	* 52.7	* 29.1
8	* 0.0	* 0.0	* 0.0	* 0.0	53.5	29.4
9	* 0.0	* 0.0	50.3	29.5	* 55.0	* 29.4
10	* 0.0	* 0.0	50.8	29.4	* 56.5	* 29.5
11	47.8	29.3	51.5	29.5	58.1	29.5
12	* 49.2	* 29.2	51.2	29.4	57.5	30.0
13	50.7	29.1	* 52.6	* 29.2	56.0	29.4
14	* 50.9	* 29.1	54.0	29.0	* 56.5	* 29.7
15	* 51.2	* 29.2	54.7	29.3	* 57.0	* 30.0
16	51.5	29.3	54.8	29.0	57.6	30.4
17	* 50.3	* 29.3	52.5	29.1	58.1	30.2
18	49.1	29.4	55.3	28.6	57.0	29.5
19	49.3	29.5	49.0	29.1	51.2	29.7
20	46.5	29.3	48.8	29.3	58.0	28.9
21	47.0	29.3	48.9	29.1	* 54.5	* 29.3
22	* 47.2	* 29.4	51.3	28.2	51.0	29.7
23	47.4	29.5	50.0	28.5	58.0	29.0
24	47.5	29.9	50.1	28.8	* 59.2	* 28.7
25	48.3	29.3	51.0	28.4	60.5	28.4
26	50.2	28.8	* 52.2	* 28.4	* 60.3	* 27.5
27	49.3	29.1	* 53.5	* 28.4	60.0	26.5
28	* 0.0	* 0.0	54.8	28.4	59.3	26.4
29	* 0.0	* 0.0	* 56.1	* 29.4	61.5	26.5
30	* 0.0	* 0.0	57.5	30.4	58.4	28.5
31	0.0	0.0	* 55.9	* 29.7	0.0	0.0
MEANS	48.9	29.3	52.0	29.1	56.3	28.8
OBSVNS.	19	19	18	18	21	21
MAXIMUM	51.8	29.9	57.5	30.4	61.5	30.4
MINIMUM	45.7	28.8	48.8	28.2	51.0	26.4
STD.DEV.	1.87	.22	2.56	.53	3.22	1.16

CAPE MUDGE 49 59 56 N 125 11 38 W

	JULY		AUGUST		SEPTEMBER	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	54.0	28.0	64.1	27.7	58.5	26.8
2	57.3	26.9	61.5	26.9	* 58.6	* 26.7
3	52.7	27.6	57.8	26.1	* 58.8	* 26.5
4	58.5	27.4	54.4	27.6	58.9	26.4
5	55.5	27.1	57.7	26.5	58.4	26.9
6	56.2	26.9	58.5	26.8	60.6	27.4
7	58.3	26.7	60.8	26.8	53.5	28.0
8	59.1	26.5	58.3	26.5	54.4	27.3
9	60.7	27.1	* 58.4	* 26.8	57.9	27.1
10	* 61.8	* 26.9	58.6	27.2	56.3	28.0
11	* 62.9	* 26.6	58.0	27.1	52.3	28.2
12	64.0	26.3	54.3	28.2	52.8	28.6
13	58.5	26.9	56.9	28.2	52.2	28.6
14	63.5	26.7	55.9	27.8	54.0	28.9
15	60.8	27.1	60.7	26.8	49.6	28.6
16	* 0.0	* 0.0	55.2	27.6	50.0	28.6
17	* 0.0	* 0.0	61.3	25.1	50.7	28.2
18	* 0.0	* 0.0	56.9	28.5	51.7	28.2
19	* 0.0	* 0.0	54.6	27.8	* 53.2	* 28.3
20	* 0.0	* 0.0	58.3	27.4	54.8	28.4
21	* 0.0	* 0.0	58.4	27.4	55.6	28.1
22	56.5	26.7	59.2	27.7	* 0.0	* 0.0
23	57.7	26.0	* 59.5	* 27.6	* 0.0	* 0.0
24	57.3	26.4	* 59.8	* 27.4	* 0.0	* 0.0
25	58.5	27.1	60.2	27.2	56.7	28.0
26	57.5	26.9	58.0	27.7	57.3	28.0
27	57.2	27.6	56.8	27.7	57.1	27.8
28	* 58.3	* 27.4	59.2	27.4	53.9	28.2
29	59.4	27.2	60.8	26.3	49.0	28.0
30	60.5	27.4	59.2	27.3	51.2	28.0
31	64.4	26.0	60.8	26.5	0.0	0.0
MEANS	58.5	26.9	58.4	27.2	54.5	27.9
OBSVNS.	22	22	28	28	24	24
MAXIMUM	64.4	28.0	64.1	28.5	60.6	28.9
MINIMUM	52.7	26.0	54.3	25.1	49.0	26.4
STD.DEV.	2.96	.51	2.36	.73	3.27	.64

CAPE MUDGE 49 59 56 N 125 11 38 W

	OCTOBER		NOVEMBER		DECEMBER	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	51.3	27.6	* 48.2	* 28.0	* 46.1	* 27.9
2	49.5	27.8	48.7	27.8	46.5	28.1
3	* 49.9	* 28.0	49.0	27.4	46.7	28.4
4	50.3	28.2	48.9	27.8	45.7	28.0
5	51.3	28.0	49.4	28.0	* 46.1	* 28.1
6	51.1	27.7	* 49.2	* 28.0	* 46.5	* 28.3
7	* 51.9	* 28.3	48.9	28.1	46.9	28.4
8	52.8	28.9	* 0.0	* 0.0	46.3	28.6
9	53.2	28.8	* 0.0	* 0.0	45.2	28.6
10	51.0	28.4	* 0.0	* 0.0	* 0.0	* 0.0
11	53.9	29.1	* 0.0	* 0.0	* 0.0	* 0.0
12	* 52.5	* 29.0	* 0.0	* 0.0	* 0.0	* 0.0
13	51.0	28.8	47.6	28.9	* 0.0	* 0.0
14	51.0	28.6	47.0	27.8	* 0.0	* 0.0
15	49.3	28.5	* 46.8	* 27.9	45.8	28.0
16	48.6	28.6	* 46.6	* 28.1	45.0	27.7
17	48.8	28.6	46.4	28.2	45.8	28.5
18	50.1	28.6	44.3	28.1	46.3	28.2
19	50.7	28.6	46.2	28.0	46.4	28.4
20	50.5	28.2	46.0	28.1	46.8	28.5
21	* 50.8	* 28.4	47.1	28.2	46.7	28.8
22	* 51.1	* 28.7	46.8	28.8	46.6	28.8
23	51.4	28.9	42.9	28.2	46.7	28.8
24	* 0.0	* 0.0	46.3	28.8	46.9	29.0
25	* 0.0	* 0.0	47.1	28.9	* 46.8	* 29.2
26	* 0.0	* 0.0	47.2	29.1	46.7	29.5
27	* 0.0	* 0.0	* 46.8	* 28.7	46.2	29.4
28	* 0.0	* 0.0	46.4	28.2	* 44.9	* 28.9
29	* 0.0	* 0.0	46.4	28.4	43.6	28.4
30	49.2	28.0	45.7	27.8	43.8	28.6
31	47.8	28.1	0.0	0.0	43.5	28.5
MEANS	50.6	28.4	46.9	28.2	45.9	28.5
OBSVNS.	20	20	20	20	21	21
YRLY.MEANS..					51.0	28.4
MAXIMUM	53.9	29.1	49.4	29.1	46.9	29.5
MINIMUM	47.8	27.6	42.9	27.4	43.5	27.7
STD.DEV.	1.54	.43	1.61	.45	1.09	.43

SISTERS ISLAND 49 29 13 N 124 26 00 W

	JANUARY		FEBRUARY		MARCH	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	45.4	29.1	44.3	29.0	46.0	29.4
2	45.0	29.0	45.0	29.5	45.3	29.1
3	45.1	29.4	44.4	29.1	46.1	29.1
4	44.8	29.4	44.5	29.0	45.9	29.3
5	44.7	29.4	44.5	29.1	45.7	29.5
6	44.2	29.4	45.2	29.8	45.2	29.3
7	44.3	29.5	45.5	29.8	45.4	29.3
8	44.0	29.8	45.2	29.1	45.6	29.4
9	43.7	29.5	45.0	29.8	45.5	29.8
10	43.7	29.3	45.5	30.0	45.4	29.3
11	43.1	29.0	46.0	30.4	45.5	29.1
12	43.0	28.9	45.5	30.3	45.0	29.0
13	43.0	28.9	45.5	29.4	45.1	29.8
14	44.2	29.0	46.0	29.8	45.2	29.1
15	44.3	29.0	46.2	29.3	45.4	29.8
16	44.5	29.1	46.7	29.1	45.5	29.1
17	45.5	30.0	47.0	29.1	46.0	29.5
18	45.0	30.0	45.6	29.0	46.2	29.0
19	44.6	30.0	45.3	29.3	46.0	29.1
20	44.6	28.4	46.0	29.4	45.5	29.1
21	44.4	28.5	46.3	29.4	45.5	29.0
22	44.2	28.6	46.0	29.4	45.5	29.1
23	44.0	28.9	45.3	29.9	45.2	29.0
24	44.2	29.0	45.5	29.4	45.0	29.0
25	43.8	28.9	45.5	29.4	45.2	29.0
26	43.4	28.9	45.0	29.3	45.5	29.0
27	43.5	28.9	46.0	29.3	46.2	29.1
28	43.7	28.9	46.0	29.7	45.5	29.3
29	43.5	28.9	0.0	0.0	45.8	29.0
30	43.6	28.9	0.0	0.0	46.2	29.3
31	44.2	28.8	0.0	0.0	46.5	29.3
MEANS	44.2	29.1	45.5	29.5	45.6	29.2
OBSVNS.	31	31	28	28	31	31
MAXIMUM	45.5	30.0	47.0	30.4	46.5	29.8
MINIMUM	43.0	28.4	44.3	29.0	45.0	29.0
STD.DEV.	.67	.42	.67	.38	.39	.24

SISTERS ISLAND 49 29 13 N 124 26 00 W

	APRIL		MAY		JUNE		1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL	
1	46.3	29.3	57.6	30.6	53.8	23.1	
2	47.2	29.0	56.6	30.4	53.5	24.8	
3	47.6	29.7	55.3	30.4	54.5	24.6	
4	46.5	29.5	55.3	31.1	53.2	27.1	
5	46.8	29.4	48.8	30.4	54.0	26.8	
6	47.7	29.7	50.0	30.0	55.4	25.8	
7	48.1	29.9	51.5	29.3	55.9	26.4	
8	48.1	29.5	52.7	30.6	55.3	27.6	
9	47.5	29.8	53.2	28.2	55.2	27.6	
10	46.8	29.7	53.0	29.7	56.2	26.9	
11	46.8	29.7	54.5	28.6	56.3	27.6	
12	47.0	29.8	54.3	29.0	57.6	27.7	
13	47.4	30.3	54.0	28.9	59.3	28.1	
14	47.3	29.5	52.1	29.9	60.3	27.6	
15	48.5	29.1	53.8	30.0	61.3	27.3	
16	48.9	30.0	54.9	28.9	62.1	27.2	
17	47.8	29.9	54.5	27.6	63.8	27.1	
18	48.4	30.2	56.4	25.6	62.6	27.3	
19	48.5	30.2	57.5	23.0	63.4	26.7	
20	49.6	30.4	56.1	22.7	62.3	26.4	
21	47.7	30.2	55.0	26.4	60.5	25.6	
22	47.6	30.3	55.5	25.8	57.0	27.1	
23	47.9	30.2	54.4	26.5	61.8	20.6	
24	49.4	30.3	53.0	29.8	60.7	22.0	
25	51.7	30.2	55.0	25.8	60.5	23.8	
26	49.1	30.0	53.5	26.8	59.8	22.0	
27	49.7	30.3	53.0	28.2	62.3	24.0	
28	51.2	30.4	53.5	28.5	65.0	23.3	
29	52.4	30.0	55.5	23.9	61.0	24.3	
30	55.1	30.6	54.4	23.9	63.0	25.0	
31	0.0	0.0	54.7	24.6	0.0	0.0	
MEANS	48.5	29.9	54.2	27.9	58.9	25.7	
OBSVNS.	30	30	31	31	30	30	
MAXIMUM	55.1	30.6	57.6	31.1	65.0	28.1	
MINIMUM	46.3	29.0	48.8	22.7	53.2	20.6	
STD.DEV.	1.94	.41	1.93	2.47	3.59	2.03	

SISTERS ISLAND 49 29 13 N 124 26 00 W

	JULY		AUGUST		SEPTEMBER 1977	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	61.6	25.4	64.3	25.0	59.0	26.9
2	60.7	26.5	64.9	25.0	59.0	26.8
3	58.5	27.1	65.5	25.8	58.8	27.1
4	59.6	26.7	64.5	25.4	58.5	26.9
5	57.8	27.3	66.5	25.4	58.3	27.4
6	59.5	27.2	68.0	25.5	59.4	27.6
7	62.1	24.3	66.0	26.3	59.5	27.4
8	62.5	24.8	64.4	26.3	60.7	27.1
9	63.4	24.7	66.3	25.9	60.3	27.3
10	63.9	23.8	67.5	25.8	59.6	27.3
11	64.0	24.6	67.7	26.7	60.1	27.7
12	62.9	25.5	64.5	26.8	59.5	27.6
13	63.6	24.3	67.9	26.4	57.4	27.3
14	63.9	23.5	69.5	26.4	55.4	27.8
15	64.3	24.8	70.5	26.4	58.9	27.7
16	63.4	25.0	67.5	26.4	56.4	27.2
17	62.1	25.9	66.2	26.4	56.6	27.6
18	63.6	26.0	66.4	26.5	56.6	27.4
19	64.5	26.0	65.7	26.3	55.9	27.6
20	64.0	24.8	66.3	26.8	55.4	28.5
21	62.6	25.8	65.8	26.3	56.1	28.5
22	63.8	25.6	64.1	26.4	56.5	26.7
23	62.2	25.9	61.5	25.8	55.6	27.7
24	63.0	26.1	58.0	27.2	56.0	27.2
25	65.5	25.4	59.5	26.3	57.0	28.0
26	66.4	25.9	60.0	25.8	55.7	27.4
27	66.7	25.5	61.2	23.8	55.6	28.0
28	65.4	25.8	60.2	25.5	55.0	28.2
29	64.5	25.5	60.3	25.1	54.9	28.4
30	64.0	25.4	60.1	26.3	55.0	28.4
31	63.7	25.4	60.0	26.1	0.0	0.0
MEANS	63.0	25.5	64.5	26.0	57.4	27.6
OBSVNS.	31	31	31	31	30	30
MAXIMUM	66.7	27.3	70.5	27.2	60.7	28.5
MINIMUM	57.8	23.5	58.0	23.8	54.9	26.7
STD.DEV.	2.09	.92	3.27	.68	1.86	.50

SISTERS ISLAND 49 29 13 N 124 26 00 W

	OCTOBER		NOVEMBER		DECEMBER 1977	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	55.2	28.0	49.6	29.3	46.4	29.1
2	54.0	28.2	49.5	29.1	46.0	29.0
3	54.0	28.1	49.0	29.5	46.4	29.0
4	54.0	28.4	49.0	29.5	45.7	29.0
5	54.0	28.1	48.5	28.9	45.7	29.0
6	53.8	28.2	48.8	29.1	46.0	29.1
7	54.0	28.1	48.6	29.1	45.0	29.1
8	54.4	28.1	48.4	29.3	44.8	29.1
9	53.3	28.2	48.4	29.1	44.5	28.9
10	53.5	28.2	49.0	29.7	45.5	29.0
11	54.2	28.2	48.8	29.3	46.4	29.1
12	53.0	29.0	* 48.6	* 29.5	45.8	29.0
13	52.3	28.5	48.3	29.7	46.0	29.1
14	52.2	28.9	48.2	29.4	46.0	28.9
15	51.9	28.9	48.0	29.3	45.0	28.8
16	51.5	28.8	47.8	29.4	45.2	28.8
17	52.0	28.9	47.3	29.4	45.1	28.6
18	52.5	29.5	47.7	29.8	44.0	28.4
19	52.3	28.9	46.7	29.3	43.5	28.4
20	52.3	28.8	45.6	29.1	44.5	28.8
21	51.6	28.4	45.4	29.3	45.0	28.9
22	50.8	29.8	45.2	29.3	45.5	28.8
23	50.9	29.9	45.2	29.4	43.5	28.8
24	50.4	29.7	46.6	29.5	43.5	28.9
25	50.5	30.0	45.8	29.5	44.5	28.9
26	50.7	29.4	46.0	30.0	43.7	28.8
27	50.3	30.2	46.4	29.8	43.4	28.8
28	50.0	29.5	46.7	29.9	43.2	28.6
29	50.2	29.9	46.5	29.1	42.5	28.5
30	49.8	29.3	46.7	29.1	42.5	28.4
31	50.0	28.6	0.0	0.0	42.7	27.7
MEANS	52.2	28.9	47.5	29.4	44.8	28.8
OBSVNS.	31	31	29	29	31	31
YRLY.MEANS......................................					52.3	28.1
MAXIMUM	55.2	30.2	49.6	30.0	46.4	29.1
MINIMUM	49.8	28.0	45.2	28.9	42.5	27.7
STD.DEV.	1.59	.68	1.37	.27	1.21	.30

CHROME ISLAND 49 28 20 N 124 40 57 W

	JANUARY		FEBRUARY		MARCH	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	44.0	27.3	45.4	29.0	45.7	27.4
2	46.1	29.8	45.7	28.9	45.4	29.0
3	45.5	29.3	45.5	28.8	46.6	29.0
4	45.0	29.0	46.3	29.4	46.0	29.5
5	45.0	29.5	46.3	29.7	46.0	29.5
6	44.8	30.0	46.3	29.7	46.0	29.3
7	44.5	29.9	46.5	29.5	46.0	29.4
8	44.8	29.1	46.5	29.5	46.0	29.5
9	45.2	30.0	46.2	29.3	46.3	29.7
10	44.5	29.5	46.8	29.5	43.5	22.2
11	44.9	29.0	47.0	29.7	46.0	29.8
12	44.8	29.1	47.2	29.9	45.5	29.9
13	44.7	29.5	45.5	26.5	43.0	25.8
14	44.3	28.5	46.3	28.4	45.5	29.4
15	45.5	29.9	46.5	28.8	46.3	29.8
16	45.5	29.1	46.6	28.8	45.8	29.7
17	46.5	29.4	47.0	29.5	47.0	29.3
18	46.7	30.0	47.0	29.0	46.5	29.3
19	46.8	29.4	47.2	29.0	46.3	29.7
20	45.7	29.1	46.8	28.8	45.9	29.5
21	46.0	28.6	46.6	29.0	46.1	29.9
22	44.6	28.6	46.3	29.1	46.0	30.2
23	45.2	29.3	46.0	28.6	46.0	30.3
24	45.2	28.9	46.4	28.5	45.3	30.3
25	44.6	28.9	45.9	28.9	45.3	30.0
26	43.6	29.1	45.6	29.0	45.7	30.6
27	42.7	28.4	46.6	29.5	45.6	30.4
28	43.2	28.6	46.7	29.4	45.8	29.8
29	43.4	28.8	0.0	0.0	46.5	29.9
30	43.5	29.4	0.0	0.0	46.8	29.8
31	44.6	29.3	0.0	0.0	47.7	30.0
MEANS	44.9	29.2	46.4	29.1	45.9	29.3
OBSVNS.	31	31	28	28	31	31
MAXIMUM	46.8	30.0	47.2	29.9	47.7	30.6
MINIMUM	42.7	27.3	45.4	26.5	43.0	22.2
STD.DEV.	.99	.58	.51	.64	.87	1.59

CHROME ISLAND 49 28 20 N 124 40 57 W

	APRIL		MAY		JUNE	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	48.3	29.8	54.0	29.0	52.2	29.1
2	47.6	30.2	51.6	29.0	53.4	29.7
3	47.6	30.0	50.5	29.5	* 53.7	* 29.1
4	48.4	29.9	49.6	29.3	54.0	28.4
5	47.8	29.9	49.4	29.8	54.2	29.0
6	48.3	29.5	50.2	30.4	54.5	28.5
7	47.5	29.9	50.0	29.3	55.8	28.2
8	47.5	29.9	51.5	29.4	57.8	26.5
9	47.1	30.0	50.8	29.7	58.0	27.7
10	46.8	29.9	53.4	29.4	59.5	28.8
11	47.0	29.4	54.2	29.3	58.4	27.8
12	47.2	30.3	53.0	29.4	60.8	27.8
13	47.4	30.6	52.2	29.9	61.0	28.2
14	46.6	30.2	51.2	29.9	62.2	27.8
15	47.2	30.4	51.5	30.2	62.0	28.4
16	47.5	30.2	52.6	29.9	62.8	28.0
17	47.8	30.6	54.0	29.7	63.2	28.1
18	47.9	30.7	53.8	29.9	63.0	28.4
19	48.7	30.0	52.6	29.9	58.6	28.4
20	48.3	30.6	54.4	30.3	57.8	28.8
21	48.3	29.9	51.8	29.9	58.5	28.9
22	48.6	30.3	54.0	29.7	57.6	28.5
23	48.3	29.5	53.2	29.3	55.8	29.1
24	48.1	26.9	53.6	29.9	57.4	28.8
25	49.5	30.4	54.2	29.9	57.6	29.7
26	49.2	30.3	53.5	29.3	56.8	28.9
27	48.6	29.9	51.0	30.0	59.0	28.1
28	51.3	29.7	52.4	29.9	58.2	28.6
29	52.6	30.3	51.6	30.6	60.2	27.8
30	54.0	30.0	51.8	29.9	61.0	26.5
31	0.0	0.0	51.0	29.3	0.0	0.0
MEANS	48.4	30.0	52.2	29.7	58.3	28.4
OBSVNS.	30	30	31	31	29	29
MAXIMUM	54.0	30.7	54.4	30.6	63.2	29.7
MINIMUM	46.8	26.9	49.4	29.0	52.2	26.5
STD.DEV.	1.63	.67	1.49	.39	2.99	.74

CHROME ISLAND 49 28 20 N 124 40 57 W

	JULY		AUGUST		SEPTEMBER 1977	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	61.2	27.4	63.8	28.1	60.8	28.1
2	59.5	27.8	64.2	28.1	59.6	28.1
3	57.3	28.2	65.2	26.9	57.8	28.0
4	58.0	28.5	66.4	26.5	58.0	28.2
5	57.2	28.9	68.2	26.1	58.2	28.2
6	57.6	28.9	68.0	26.5	58.8	29.3
7	60.0	28.8	69.8	27.1	59.2	28.0
8	60.3	29.0	69.6	26.0	60.6	28.1
9	58.0	29.5	69.6	26.0	61.2	28.0
10	62.5	28.4	70.2	26.4	61.4	28.1
11	60.3	29.5	69.4	25.9	61.2	27.8
12	61.7	29.1	68.9	26.1	61.8	28.2
13	60.6	29.3	68.8	26.7	61.5	28.4
14	62.8	29.0	69.2	27.1	61.6	27.6
15	63.5	28.2	68.2	26.9	58.5	27.7
16	61.9	28.0	68.8	26.9	57.2	28.0
17	58.5	28.8	66.6	26.7	57.5	27.4
18	61.4	28.2	65.2	27.8	56.5	28.6
19	64.2	26.4	66.0	28.2	55.2	28.8
20	62.4	26.7	64.2	27.8	54.5	29.7
21	62.6	27.7	64.4	28.4	53.5	29.3
22	63.7	25.6	61.0	27.8	53.2	29.1
23	64.4	27.2	59.2	29.3	53.4	28.9
24	65.8	27.3	55.5	28.8	52.6	29.9
25	66.0	27.4	57.6	29.0	54.2	29.0
26	65.5	27.3	58.6	28.8	53.4	29.1
27	64.6	27.4	58.4	28.6	55.0	28.8
28	58.0	28.6	58.0	27.4	55.5	28.2
29	54.6	28.8	58.6	29.0	55.2	29.3
30	56.6	29.0	59.4	28.0	55.8	28.2
31	60.6	29.5	61.5	27.7	0.0	0.0
MEANS	61.0	28.2	64.6	27.4	57.4	28.5
OBSVNS.	31	31	31	31	30	30
MAXIMUM	66.0	29.5	70.2	29.3	61.8	29.9
MINIMUM	54.6	25.6	55.5	25.9	52.6	27.4
STD.DEV.	2.98	.98	4.54	1.03	3.01	.64

CHROME ISLAND 49 28 20 N 124 40 57 W

	OCTOBER		NOVEMBER		DECEMBER	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	55.0	27.8	49.6	29.1	47.2	29.4
2	54.4	28.5	47.8	27.8	47.2	29.9
3	54.2	29.5	47.2	26.7	46.2	28.2
4	54.0	28.5	48.4	29.3	46.0	29.4
5	54.8	28.8	48.0	28.4	46.0	29.0
6	54.5	28.6	* 48.3	* 28.6	46.2	29.1
7	54.8	28.4	48.6	28.9	46.2	29.8
8	54.8	28.2	48.2	29.3	44.8	29.4
9	54.0	28.8	47.8	29.0	44.6	29.7
10	53.5	28.8	49.4	29.5	45.2	29.1
11	54.3	28.9	48.8	29.3	46.4	29.1
12	53.2	29.0	48.6	29.8	46.6	29.5
13	53.2	28.9	48.0	29.5	46.4	29.9
14	52.4	29.8	47.2	25.4	46.0	28.9
15	52.4	29.0	47.8	29.0	46.0	29.7
16	51.2	29.5	46.6	28.4	46.4	28.5
17	51.2	29.8	46.4	29.1	46.0	29.0
18	52.0	29.1	45.8	28.0	45.8	28.8
19	51.5	29.7	46.2	28.9	45.8	28.8
20	51.5	29.1	46.0	28.9	44.4	28.6
21	51.4	29.3	45.6	28.8	44.0	28.6
22	50.8	29.8	45.4	28.8	44.8	28.2
23	50.5	30.0	46.0	28.2	44.4	28.2
24	50.4	30.3	46.2	29.3	44.8	28.4
25	50.0	29.8	46.4	28.9	44.6	28.5
26	49.8	30.0	45.5	28.9	44.0	28.4
27	49.8	29.9	47.0	29.1	43.8	28.6
28	49.6	30.0	* 47.0	* 29.2	43.0	28.9
29	49.6	29.5	47.0	29.4	43.0	28.5
30	49.6	30.2	46.6	28.6	43.8	29.1
31	48.8	27.8	0.0	0.0	43.2	28.4
MEANS	52.2	29.2	47.2	28.7	45.3	29.0
OBSVNS.	31	31	28	28	31	31
YRLY.MEANS..					52.0	28.9
MAXIMUM	55.0	30.3	49.6	29.8	47.2	29.9
MINIMUM	48.8	27.8	45.4	25.4	43.0	28.2
STD.DEV.	1.97	.69	1.21	.90	1.21	.53

DEPARTURE BAY 49 12 38 N 123 57 17 W

	JANUARY		FEBRUARY		MARCH	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.0	* 44.6	* 28.3	50.0	28.27
2	* 0.0	* 0.0	46.4	28.5	46.4	27.24
3	* 0.0	* 0.0	45.5	28.2	48.2	28.40
4	43.5	28.0	43.2	28.0	* 0.0	* 0.00
5	43.7	28.0	46.4	28.0	* 0.0	* 0.00
6	43.2	28.0	* 45.5	* 28.1	* 0.0	* 0.00
7	44.8	28.6	44.6	* 28.2	46.4	* 0.00
8	* 43.9	* 28.1	46.4	28.39 †	46.4	* 0.00
9	* 42.9	* 27.6	46.4	29.07	44.6	* 0.00
10	41.9	27.1	48.2	28.18	46.4	29.29
11	43.2	28.0	46.4	28.63	44.6	23.84
12	43.3	28.0	* 45.8	* 28.33	* 44.0	* 24.70
13	42.3	26.7	* 45.2	* 28.03	* 43.4	* 25.57
14	43.0	25.6	44.6	27.72	42.8	26.44
15	* 44.7	* 26.1	* 46.4	* 28.05	46.4	27.52
16	* 46.4	* 26.6	48.2	28.38	48.2	28.04
17	48.2	27.2	50.0	28.13	* 0.0	* 0.00
18	48.6	28.8	* 0.0	* 0.00	* 0.0	* 0.00
19	47.3	25.1	* 0.0	* 0.00	* 0.0	* 0.00
20	43.5	26.9	* 0.0	* 0.00	* 0.0	* 0.00
21	46.9	28.0	46.4	27.77	* 0.0	* 0.00
22	* 45.6	* 28.0	46.4	28.60	* 0.0	* 0.00
23	* 44.2	* 28.1	44.6	29.09	* 0.0	* 0.00
24	42.8	28.2	46.4	29.00	* 0.0	* 0.00
25	42.8	28.1	44.6	27.92	* 0.0	* 0.00
26	43.0	27.6	* 45.2	* 27.62	* 0.0	* 0.00
27	43.3	27.6	* 45.8	* 27.32	* 0.0	* 0.00
28	* 0.0	* 0.0	46.4	27.02	* 0.0	* 0.00
29	* 0.0	* 0.0	0.0	0.00	* 0.0	* 0.00
30	* 0.0	* 0.0	0.0	0.00	* 0.0	* 0.00
31	42.8	28.2	0.0	0.00	* 0.0	* 0.00
MEANS	44.1	27.6	46.4	28.27	46.4	27.38
OBSVNS.	19	19	18	17	11	8
MAXIMUM	48.6	28.8	50.0	29.09	50.0	29.29
MINIMUM	41.9	25.1	44.6	27.02	42.8	23.84
STD.DEV.	2.04	.95	1.46	.53	1.97	1.66

† From February 8 onward, salinities at Departure Bay were determined by salinometer.

DEPARTURE BAY 49 12 38 N 123 57 17 W

DATE	APRIL TEMP	APRIL SAL	MAY TEMP	MAY SAL	JUNE TEMP	JUNE SAL 1977
1	* 0.0	* 0.00	* 54.1	* 27.34	54.5	28.00
2	* 0.0	* 0.00	54.1	27.07	58.1	22.61
3	* 0.0	* 0.00	52.7	26.82	55.4	23.63
4	* 0.0	* 0.00	49.1	28.81	* 56.3	* 24.04
5	* 0.0	* 0.00	49.1	28.85	* 57.2	* 24.46
6	* 0.0	* 0.00	50.9	27.38	58.1	24.88
7	* 0.0	* 0.00	* 51.5	* 27.35	60.6	23.75
8	* 0.0	* 0.00	* 52.1	* 27.32	60.8	23.80
9	* 0.0	* 0.00	52.7	27.29	59.5	25.02
10	* 0.0	* 0.00	54.5	27.54	61.5	25.28
11	* 0.0	* 0.00	54.5	26.07	* 62.1	* 25.28
12	* 0.0	26.88	54.5	26.99	* 62.8	* 25.28
13	48.2	29.42	52.7	27.85	63.5	25.28
14	46.9	29.27	* 53.9	* 26.17	63.9	24.24
15	47.7	28.27	* 55.1	* 24.48	66.2	24.93
16	* 47.3	* 28.57	56.3	22.79	64.0	26.51
17	* 46.9	* 28.87	55.4	26.35	65.8	26.05
18	46.4	29.17	55.4	27.86	* 63.9	* 26.18
19	47.3	28.46	56.3	26.76	* 62.0	* 26.32
20	48.4	28.69	54.5	27.22	60.1	26.46
21	49.5	28.67	* 0.0	* 0.00	59.9	26.61
22	* 0.0	* 0.00	* 0.0	* 0.00	53.6	28.66
23	* 0.0	* 0.00	* 0.0	* 0.00	58.1	25.74
24	* 0.0	* 0.00	56.5	19.79	58.1	26.19
25	53.1	27.15	58.1	20.25	* 59.6	* 24.14
26	54.5	26.00	55.4	23.20	* 61.1	* 22.08
27	51.3	28.47	50.9	27.95	62.6	20.02
28	54.5	28.32	* 51.8	* 27.56	63.9	24.12
29	54.0	27.86	* 52.7	* 27.16	62.6	22.29
30	* 54.0	* 27.60	53.6	26.76	* 0.0	* 0.00
31	0.0	0.00	54.5	26.75	0.0	0.00
MEANS	50.2	28.20	53.9	26.21	60.5	24.96
OBSVNS.	12	13	21	21	21	21
MAXIMUM	54.5	29.42	58.1	28.85	66.2	28.66
MINIMUM	46.4	26.00	49.1	19.79	53.6	20.02
STD.DEV.	3.14	.96	2.38	2.53	3.53	1.96

DEPARTURE BAY 49 12 38 N 123 57 17 W

	JULY		AUGUST		SEPTEMBER 1977	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	* 0.0	* 0.00	* 0.0	* 0.00	59.0	23.76
2	* 0.0	* 0.00	67.1	18.32	59.0	24.59
3	* 0.0	* 0.00	67.1	20.79	* 0.0	* 0.00
4	59.0	25.17	66.2	23.28	* 0.0	* 0.00
5	58.1	25.86	* 0.0	* 0.00	* 0.0	* 0.00
6	60.4	27.10	* 0.0	* 0.00	63.1	24.06
7	63.3	25.00	* 0.0	* 0.00	60.8	24.08
8	62.6	26.10	70.7	25.13	63.1	24.65
9	* 63.2	* 25.59	71.2	24.07	63.1	25.22
10	* 63.8	* 25.07	71.6	24.16	* 63.1	* 25.54
11	64.4	24.55	71.2	24.99	* 63.1	* 25.87
12	62.6	25.08	69.8	25.74	63.1	26.20
13	62.6	23.86	* 68.6	* 25.89	62.6	26.86
14	61.7	26.25	* 67.4	* 26.04	59.0	28.97
15	65.7	23.60	66.2	26.20	59.0	28.97
16	* 63.9	* 23.61	66.2	26.56	57.2	27.30
17	* 62.1	* 23.63	67.1	26.48	* 56.5	* 27.27
18	60.3	23.64	68.0	26.51	* 55.7	* 27.23
19	62.1	20.13	63.5	27.32	54.9	27.19
20	62.6	20.76	* 61.7	* 27.69	53.6	28.67
21	63.0	22.11	* 59.9	* 28.06	54.1	28.85
22	62.6	23.65	58.1	28.43	55.4	27.39
23	* 64.7	* 23.10	58.1	28.30	54.5	27.54
24	* 66.8	* 22.55	54.7	28.61	* 54.8	* 27.76
25	68.9	22.00	54.5	28.78	* 55.1	* 27.98
26	66.7	23.98	* 0.0	* 0.00	55.4	28.20
27	65.7	25.47	* 0.0	* 0.00	55.4	26.17
28	61.7	26.83	* 0.0	* 0.00	57.2	25.53
29	59.0	27.85	57.2	26.21	54.9	25.28
30	* 0.0	* 0.00	58.1	24.29	55.4	25.88
31	* 0.0	* 0.00	59.0	26.95	0.0	0.00
MEANS	62.6	24.45	64.3	25.56	58.1	26.45
OBSVNS.	20	20	20	20	21	21
MAXIMUM	68.9	27.85	71.6	28.78	63.1	28.97
MINIMUM	58.1	20.13	54.5	18.32	53.6	23.76
STD.DEV.	2.69	2.06	5.85	2.62	3.40	1.72

DEPARTURE BAY 49 12 38 N 123 57 17 W

DATE	OCTOBER TEMP	OCTOBER SAL	NOVEMBER TEMP	NOVEMBER SAL	DECEMBER 1977 TEMP	DECEMBER 1977 SAL
1	* 55.4	* 26.43	48.9	* 27.19	44.4	23.33
2	* 55.4	* 26.98	47.7	* 25.68	45.3	24.42
3	55.4	27.53	46.4	24.17	* 45.0	* 25.24
4	55.8	27.07	* 0.0	* 0.00	* 44.6	* 26.06
5	55.4	27.17	* 0.0	* 0.00	44.2	26.88
6	54.3	27.29	* 0.0	* 0.00	42.8	24.68
7	55.0	27.36	48.0	28.54	45.9	28.59
8	* 0.0	* 0.00	48.2	28.24	43.7	27.57
9	* 0.0	* 0.00	47.3	* 26.96	41.0	26.27
10	* 0.0	* 0.00	48.2	25.67	* 41.9	* 26.75
11	53.6	28.38	* 0.0	* 0.00	* 42.8	* 27.24
12	53.4	28.16	* 0.0	* 0.00	43.7	27.73
13	53.4	28.71	* 0.0	* 0.00	44.2	17.31
14	53.8	28.15	46.6	25.31	45.0	19.11
15	* 53.3	* 27.96	45.1	* 25.81	45.7	27.27
16	* 52.8	* 27.77	47.1	26.31	42.8	24.52
17	52.2	27.58	46.8	25.87	* 42.5	* 24.07
18	52.5	27.49	46.6	26.09	* 42.2	* 23.61
19	52.2	27.95	* 45.7	* 26.27	41.9	23.15
20	52.3	27.97	* 44.7	* 26.46	41.7	23.47
21	51.8	28.00	43.7	26.65	42.8	26.00
22	* 51.2	* 28.40	45.7	28.45	41.7	24.71
23	* 50.6	* 28.81	44.8	28.47	43.9	27.01
24	50.0	29.22	45.3	27.84	* 0.0	* 0.00
25	49.8	28.47	46.6	27.66	* 0.0	* 0.00
26	49.8	27.99	* 45.9	* 26.54	* 0.0	* 0.00
27	48.9	27.12	* 45.2	* 25.42	* 0.0	* 0.00
28	49.1	27.77	44.4	24.29	39.4	26.79
29	* 48.8	* 28.07	46.8	28.24	41.0	26.87
30	* 48.5	* 28.38	46.2	27.95	40.8	26.52
31	48.2	28.69	0.0	0.00	* 0.0	* 0.00
MEANS	52.3	27.90	46.5	26.86	43.1	25.11
OBSVNS.	20	20	20	16	20	20
YRLY.MEANS........					52.9	26.4
MAXIMUM	55.8	29.22	48.9	28.54	45.9	28.59
MINIMUM	48.2	27.07	43.7	24.17	39.4	17.31
STD.DEV.	2.36	.59	1.37	1.51	1.81	2.85

ENTRANCE ISLAND 49 12 34 N 123 48 27 W

	JANUARY		FEBRUARY		MARCH	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	43.1	26.3	44.2	26.0	45.7	28.1
2	45.0	27.4	43.3	27.4	45.7	28.2
3	46.1	28.6	42.6	26.4	46.2	28.9
4	45.2	28.2	44.5	27.8	45.5	28.1
5	43.0	27.4	44.5	28.4	46.2	29.3
6	42.8	27.3	44.3	27.3	46.3	29.4
7	43.0	25.0	44.2	27.6	46.4	29.8
8	43.8	27.7	44.5	27.4	46.3	29.8
9	43.6	27.6	46.1	28.9	46.5	29.5
10	43.4	28.1	46.8	29.3	45.8	28.6
11	45.0	28.5	46.6	29.1	45.8	28.8
12	43.0	27.4	47.2	29.1	45.8	28.8
13	43.2	27.4	44.5	26.7	45.3	28.6
14	45.0	28.4	44.7	26.1	45.1	28.2
15	45.6	28.8	45.7	26.4	45.7	28.6
16	45.7	28.9	45.7	26.8	45.8	28.5
17	46.2	29.0	46.2	28.2	* 45.9	* 28.5
18	47.0	29.0	46.6	28.8	46.0	28.4
19	46.1	28.8	45.3	27.8	46.6	28.6
20	44.0	24.8	46.5	28.5	45.5	28.4
21	45.4	28.2	46.6	29.0	46.2	28.6
22	43.8	27.7	46.5	29.5	46.0	28.9
23	43.8	27.8	45.3	26.1	45.9	29.0
24	43.4	27.4	45.2	26.8	45.8	29.0
25	43.5	27.6	45.3	26.9	45.9	28.9
26	43.9	27.8	45.5	28.1	46.0	29.7
27	43.3	28.0	46.4	29.0	45.8	29.5
28	43.2	28.1	45.5	27.2	45.9	29.5
29	43.6	28.2	0.0	0.0	46.3	29.4
30	42.8	27.8	0.0	0.0	46.6	29.4
31	44.0	28.1	0.0	0.0	46.8	29.5
MEANS	44.2	27.8	45.4	27.8	46.0	28.9
OBSVNS.	31	31	28	28	30	30
MAXIMUM	47.0	29.0	47.2	29.5	46.8	29.8
MINIMUM	42.8	24.8	42.6	26.1	45.1	28.1
STD.DEV.	1.20	.98	1.13	1.04	.39	.52

ENTRANCE ISLAND 49 12 34 N 123 48 27 W

	APRIL		MAY		JUNE	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	47.5	29.7	54.3	28.2	53.4	27.8
2	47.3	29.1	51.8	28.6	55.6	24.2
3	47.3	29.1	49.7	29.0	52.6	27.1
4	47.7	29.3	49.3	29.4	51.1	28.5
5	48.5	29.1	52.6	26.7	57.0	26.1
6	48.6	29.3	54.0	22.1	55.5	26.8
7	48.3	29.3	56.4	22.9	60.5	22.5
8	46.8	29.4	55.0	27.1	57.7	24.0
9	46.5	29.5	52.6	28.0	57.2	25.1
10	46.6	29.4	55.3	22.9	57.3	25.9
11	46.7	29.5	55.2	23.3	59.5	25.9
12	46.7	29.7	54.0	26.7	59.3	26.8
13	47.0	29.7	50.6	28.9	60.2	26.9
14	47.0	29.7	52.0	27.8	62.1	24.7
15	47.0	29.8	53.1	27.4	62.5	25.5
16	47.5	29.8	53.4	25.0	62.8	25.8
17	47.6	29.7	53.2	28.1	64.7	20.4
18	47.7	28.8	55.0	26.1	63.7	22.0
19	48.5	29.4	53.5	28.6	56.8	27.2
20	48.4	29.3	53.6	28.1	55.5	28.0
21	48.4	29.3	50.7	28.8	54.5	28.6
22	48.9	29.3	51.8	28.4	61.3	19.6
23	50.9	29.3	52.6	28.5	59.3	20.1
24	52.8	28.9	55.9	20.9	55.5	27.6
25	51.4	28.8	56.1	20.8	55.7	28.2
26	49.8	29.3	51.6	28.2	57.8	24.8
27	49.7	29.3	49.4	29.3	61.3	24.4
28	52.6	28.2	50.1	29.4	58.6	26.9
29	53.0	28.4	55.1	20.8	62.0	17.9
30	53.6	28.5	52.2	27.8	62.5	20.6
31	0.0	0.0	51.1	27.8	0.0	0.0
MEANS	48.7	29.3	52.9	26.6	58.4	25.0
OBSVNS.	30	30	31	31	30	30
MAXIMUM	53.6	29.8	56.4	29.4	64.7	28.6
MINIMUM	46.5	28.2	49.3	20.8	51.1	17.9
STD.DEV.	2.11	.41	2.03	2.78	3.48	2.92

ENTRANCE ISLAND 49 12 34 N 123 48 27 W

	JULY		AUGUST		SEPTEMBER 1977	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	60.8	23.0	67.2	19.0	60.5	23.5
2	62.0	19.6	66.7	21.3	59.9	23.8
3	60.0	24.7	66.5	22.1	56.2	28.6
4	58.9	26.0	65.0	23.0	60.5	24.7
5	58.5	24.6	66.5	23.9	60.6	24.4
6	60.5	25.5	67.3	24.2	60.2	25.5
7	61.2	25.2	67.5	25.0	61.2	24.3
8	60.0	26.0	66.8	23.1	61.5	24.7
9	64.3	24.7	66.7	23.8	61.5	24.6
10	63.2	24.7	69.5	22.9	60.8	25.2
11	57.3	28.5	67.6	24.8	60.2	25.5
12	61.9	25.2	67.0	26.0	60.5	26.7
13	60.8	26.0	68.2	26.1	58.8	26.9
14	59.9	27.7	66.7	25.9	58.6	27.2
15	65.0	19.4	65.0	26.3	57.5	26.9
16	59.5	25.8	66.0	26.1	57.2	27.2
17	61.4	25.0	69.7	26.1	56.5	27.1
18	63.3	20.3	58.4	27.7	55.1	27.6
19	63.0	21.0	60.7	27.3	54.5	28.1
20	64.8	21.2	60.8	27.6	52.4	28.4
21	63.0	21.8	55.5	28.4	54.3	28.2
22	63.0	23.3	56.2	28.4	55.1	27.6
23	64.5	24.0	54.0	28.5	52.0	28.9
24	65.0	21.3	52.2	29.0	52.7	28.4
25	66.5	22.9	52.6	28.9	53.4	28.4
26	64.8	25.1	58.2	26.7	56.7	24.4
27	60.0	28.1	54.5	28.4	56.3	23.1
28	56.8	28.0	53.3	28.4	56.2	24.4
29	57.7	28.2	59.2	25.8	56.2	26.0
30	59.0	27.8	61.5	22.0	55.5	25.9
31	64.4	25.1	61.5	22.5	0.0	0.0
MEANS	61.6	24.5	62.5	25.5	57.4	26.2
OBSVNS.	31	31	31	31	30	30
MAXIMUM	66.5	28.5	69.7	29.0	61.5	28.9
MINIMUM	56.8	19.4	52.2	19.0	52.0	23.1
STD.DEV.	2.59	2.60	5.62	2.59	2.97	1.74

ENTRANCE ISLAND 49 12 34 N 123 48 27 W

DATE	OCTOBER TEMP	OCTOBER SAL	NOVEMBER TEMP	NOVEMBER SAL	DECEMBER 1977 TEMP	DECEMBER 1977 SAL
1	55.0	26.3	48.5	28.8	45.0	28.4
2	53.8	27.1	49.3	27.7	45.3	27.1
3	54.5	26.9	48.8	26.3	46.1	27.3
4	54.8	27.2	49.0	26.5	44.5	26.3
5	54.7	27.1	49.2	26.3	43.3	26.1
6	54.6	27.1	48.8	26.3	46.7	28.1
7	55.1	27.2	49.4	27.7	43.8	26.8
8	53.6	27.8	* 49.1	* 28.1	42.7	26.1
9	53.8	27.7	48.8	28.6	45.5	26.5
10	53.4	27.4	48.5	29.0	47.0	28.8
11	54.2	27.7	48.5	29.1	47.7	29.1
12	52.1	28.2	48.9	29.5	46.4	27.7
13	53.1	27.4	48.7	29.4	47.8	30.4
14	53.4	27.2	48.5	29.1	47.5	30.6
15	52.4	27.6	47.9	28.4	45.7	25.1
16	51.1	28.2	47.0	25.8	45.0	27.3
17	52.2	27.4	47.1	26.1	44.0	25.9
18	52.6	27.2	46.2	25.8	43.9	25.9
19	52.4	27.3	46.3	26.0	44.0	26.8
20	52.5	27.3	46.6	27.4	43.8	27.1
21	50.9	28.5	46.7	27.8	42.3	25.1
22	50.2	29.1	45.6	27.2	42.0	25.2
23	50.1	28.9	45.3	27.8	41.9	25.4
24	50.0	29.0	47.0	28.5	41.4	25.2
25	49.6	29.0	47.0	27.8	42.7	26.5
26	50.1	29.0	46.0	27.8	41.7	26.4
27	49.8	29.4	47.3	28.9	41.2	26.3
28	49.0	29.1	47.7	27.6	40.7	26.0
29	49.0	29.4	47.7	29.0	41.8	26.0
30	49.1	29.8	45.6	27.8	42.3	26.5
31	48.9	28.2	0.0	0.0	39.8	26.0
MEANS	52.1	28.0	47.7	27.7	44.0	26.8
OBSVNS.	31	31	29	29	31	31
YRLY.MEANS..					51.8	27.0
MAXIMUM	55.1	29.8	49.4	29.5	47.8	30.6
MINIMUM	48.9	26.3	45.3	25.8	39.8	25.1
STD.DEV.	2.08	.92	1.25	1.17	2.23	1.42

ACTIVE PASS 48 52 26 N 123 17 23 W

	JANUARY		FEBRUARY		MARCH	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	44.4	25.6	45.5	28.5	45.6	27.1
2	44.8	27.8	44.0	26.0	45.8	28.5
3	44.8	27.6	44.6	28.2	46.1	27.7
4	44.4	27.1	45.3	28.5	45.8	28.8
5	44.5	28.1	44.0	28.0	46.8	28.5
6	43.8	28.6	45.3	28.6	46.2	28.4
7	42.6	27.2	45.2	27.8	45.9	29.1
8	42.2	26.8	44.4	27.2	45.8	30.3
9	45.0	28.6	44.8	28.1	44.6	30.4
10	45.2	29.0	45.2	28.4	* 45.1	* 29.9
11	44.9	28.8	46.1	28.8	45.7	29.4
12	42.3	27.3	46.9	28.9	45.9	30.4
13	43.0	26.7	46.5	29.5	45.2	26.9
14	45.0	28.5	46.5	28.4	45.0	27.4
15	45.7	28.8	46.5	27.8	45.5	28.2
16	45.9	29.1	46.7	28.9	45.6	26.3
17	47.2	28.9	47.0	26.8	47.0	26.8
18	46.7	28.8	46.6	26.9	46.5	27.1
19	45.8	28.6	43.8	22.6	46.1	26.8
20	44.7	25.0	45.9	28.6	46.1	28.8
21	44.2	24.7	45.9	28.6	46.3	27.1
22	43.5	25.1	46.0	30.0	45.8	29.7
23	43.3	25.1	45.6	30.2	45.2	29.1
24	42.8	24.6	44.8	26.1	45.5	29.7
25	43.1	26.5	45.5	28.2	45.9	29.4
26	43.5	24.4	45.8	29.3	46.0	29.7
27	43.3	26.9	46.2	29.7	45.6	29.9
28	43.2	27.1	46.5	29.5	45.7	29.7
29	42.4	26.9	0.0	0.0	46.1	26.3
30	43.3	26.9	0.0	0.0	46.6	26.7
31	44.4	28.1	0.0	0.0	46.7	28.8
MEANS	44.2	27.2	45.6	28.2	45.9	28.4
OBSVNS.	31	31	28	28	30	30
MAXIMUM	47.2	29.1	47.0	30.2	47.0	30.4
MINIMUM	42.2	24.4	43.8	22.6	44.6	26.3
STD.DEV.	1.28	1.48	.91	1.49	.53	1.31

ACTIVE PASS 48 52 26 N 123 17 23 W

	APRIL		MAY		JUNE	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	47.7	28.2	54.2	13.2	48.7	29.5
2	49.2	28.5	48.9	29.4	51.5	29.5
3	48.2	28.9	50.5	30.2	50.0	29.0
4	48.2	28.6	48.8	30.0	49.8	29.1
5	46.5	28.6	49.3	29.5	56.5	22.4
6	46.6	29.4	49.3	29.1	53.1	27.1
7	47.3	29.1	49.8	28.5	58.7	16.3
8	47.7	28.9	50.0	29.5	58.9	12.9
9	46.3	29.5	49.2	29.0	58.8	18.2
10	46.5	29.5	52.6	23.4	59.4	22.7
11	47.3	29.8	51.6	27.2	58.9	26.3
12	48.0	29.7	51.8	27.8	60.1	26.4
13	47.5	29.1	49.4	27.7	61.2	23.5
14	48.9	28.2	49.9	29.3	62.1	22.2
15	48.3	29.3	51.0	29.8	55.9	27.6
16	48.5	29.1	49.8	28.6	53.8	28.6
17	48.2	28.8	50.7	28.6	57.9	28.0
18	48.9	25.2	50.0	29.4	55.8	28.0
19	46.0	28.2	50.5	29.7	57.8	24.7
20	47.8	28.9	49.0	30.2	52.7	28.5
21	47.3	29.4	51.6	29.9	52.7	29.1
22	48.8	29.8	49.8	29.5	52.7	29.5
23	47.5	28.9	49.4	29.3	54.6	25.9
24	50.0	27.1	49.6	29.1	52.3	28.1
25	50.7	21.0	50.5	28.6	53.2	29.1
26	48.8	28.8	49.9	29.8	51.7	29.5
27	51.2	28.1	49.9	29.8	54.0	28.9
28	57.5	15.4	50.2	30.3	53.8	29.7
29	50.8	28.2	52.3	29.5	62.1	15.8
30	55.7	17.6	51.2	29.4	62.0	18.6
31	0.0	0.0	48.8	29.7	0.0	0.0
MEANS	48.8	27.7	50.3	28.5	55.7	25.5
OBSVNS.	30	30	31	31	30	30
MAXIMUM	57.5	29.8	54.2	30.3	62.1	29.7
MINIMUM	46.3	15.4	48.8	13.2	48.7	12.9
STD.DEV.	2.46	3.47	1.25	3.12	3.93	4.78

ACTIVE PASS 48 52 26 N 123 17 23 W

	JULY		AUGUST		SEPTEMBER	1977
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	61.3	21.3	62.6	23.8	57.8	26.5
2	59.8	22.7	68.6	17.0	56.0	26.0
3	56.4	26.5	67.6	19.9	55.8	27.7
4	55.3	27.2	66.0	22.9	55.5	28.0
5	55.2	25.8	63.9	24.6	58.9	21.0
6	55.1	25.6	65.0	23.9	62.2	16.1
7	57.9	25.0	69.4	16.6	58.4	25.5
8	57.5	25.2	71.9	10.3	62.9	19.4
9	56.7	27.1	70.4	19.9	60.9	21.8
10	57.1	24.2	71.1	13.3	61.0	19.2
11	55.0	28.9	68.8	19.2	60.1	25.5
12	56.5	28.0	* 67.2	* 22.1	59.4	23.0
13	53.9	28.4	65.5	25.0	57.8	26.5
14	57.2	27.7	64.0	26.5	57.9	26.7
15	56.7	28.2	60.6	27.2	57.0	27.3
16	52.6	28.5	60.3	28.1	57.8	27.3
17	53.6	28.1	60.8	27.4	54.9	28.4
18	58.2	24.7	57.3	27.8	54.7	28.4
19	63.6	13.6	* 56.9	* 28.1	54.5	28.8
20	61.3	20.6	56.4	28.5	53.7	29.3
21	55.6	27.2	52.8	28.5	53.8	29.1
22	56.9	27.2	53.4	29.0	54.5	29.3
23	64.2	7.9	57.2	29.3	53.7	29.3
24	66.3	13.6	52.5	28.8	53.1	29.3
25	60.8	25.8	53.0	28.9	53.6	29.1
26	62.9	25.6	55.4	28.8	53.3	28.6
27	56.5	28.2	53.3	29.3	55.3	23.0
28	53.1	28.9	53.9	29.0	54.8	22.1
29	55.9	29.1	53.8	28.8	53.8	24.7
30	55.6	28.8	56.2	25.8	54.4	23.0
31	56.2	28.9	58.2	26.3	0.0	0.0
MEANS	57.6	25.1	61.0	24.6	56.6	25.7
OBSVNS.	31	31	29	29	30	30
MAXIMUM	66.3	29.1	71.9	29.3	62.9	29.3
MINIMUM	52.6	7.9	52.5	10.3	53.1	16.1
STD.DEV.	3.39	5.04	6.44	5.21	2.85	3.58

ACTIVE PASS 48 52 26 N 123 17 23 W

	OCTOBER		NOVEMBER		DECEMBER 197	
DATE	TEMP	SAL	TEMP	SAL	TEMP	SAL
1	54.5	28.5	49.4	29.9	44.8	27.6
2	54.0	18.7	48.3	29.9	46.1	28.8
3	54.2	26.9	49.0	29.4	46.4	28.8
4	54.5	23.4	48.8	28.9	42.8	23.0
5	54.0	24.0	49.3	29.0	43.8	24.4
6	53.8	26.5	48.8	26.8	46.8	28.8
7	54.2	28.2	48.5	28.6	45.3	28.6
8	53.3	28.8	48.1	27.6	43.5	26.9
9	52.8	24.3	48.6	28.9	43.3	27.8
10	53.2	28.1	49.3	28.4	46.2	28.8
11	53.0	27.1	48.8	30.2	47.2	28.9
12	51.8	29.0	48.4	29.8	46.4	29.5
13	53.0	26.9	48.1	30.2	46.1	29.3
14	52.8	26.8	48.0	30.6	47.0	29.9
15	52.5	27.8	47.0	30.3	46.4	29.8
16	52.2	25.4	47.2	29.3	45.1	26.7
17	51.3	29.3	45.3	23.4	44.0	26.0
18	52.1	28.6	46.3	27.3	44.7	27.3
19	51.6	28.0	43.8	26.7	45.3	27.1
20	50.6	25.2	44.7	28.6	43.0	27.1
21	51.3	29.0	44.9	29.0	40.5	19.6
22	50.9	28.8	44.2	27.3	43.1	22.1
23	51.1	29.8	43.1	27.3	42.2	23.5
24	50.4	30.2	45.1	27.4	42.3	25.9
25	50.1	29.8	45.8	27.4	42.0	23.9
26	50.3	30.3	46.1	27.3	40.5	22.2
27	50.4	29.8	45.5	27.4	41.0	23.8
28	50.3	30.0	46.3	28.8	41.2	24.7
29	48.8	30.2	46.3	28.8	42.3	26.8
30	48.8	30.4	44.5	27.2	41.6	26.1
31	48.3	30.2	0.0	0.0	42.3	28.2
MEANS	51.9	27.7	46.9	28.4	44.0	26.5
OBSVNS.	31	31	30	30	31	31
YRLY.MEANS..					50.7	27.0
MAXIMUM	54.5	30.4	49.4	30.6	47.2	29.9
MINIMUM	48.3	18.7	43.1	23.4	40.5	19.6
STD.DEV.	1.77	2.59	1.69	1.50	2.09	2.63

Annual Graphs of the 7-day

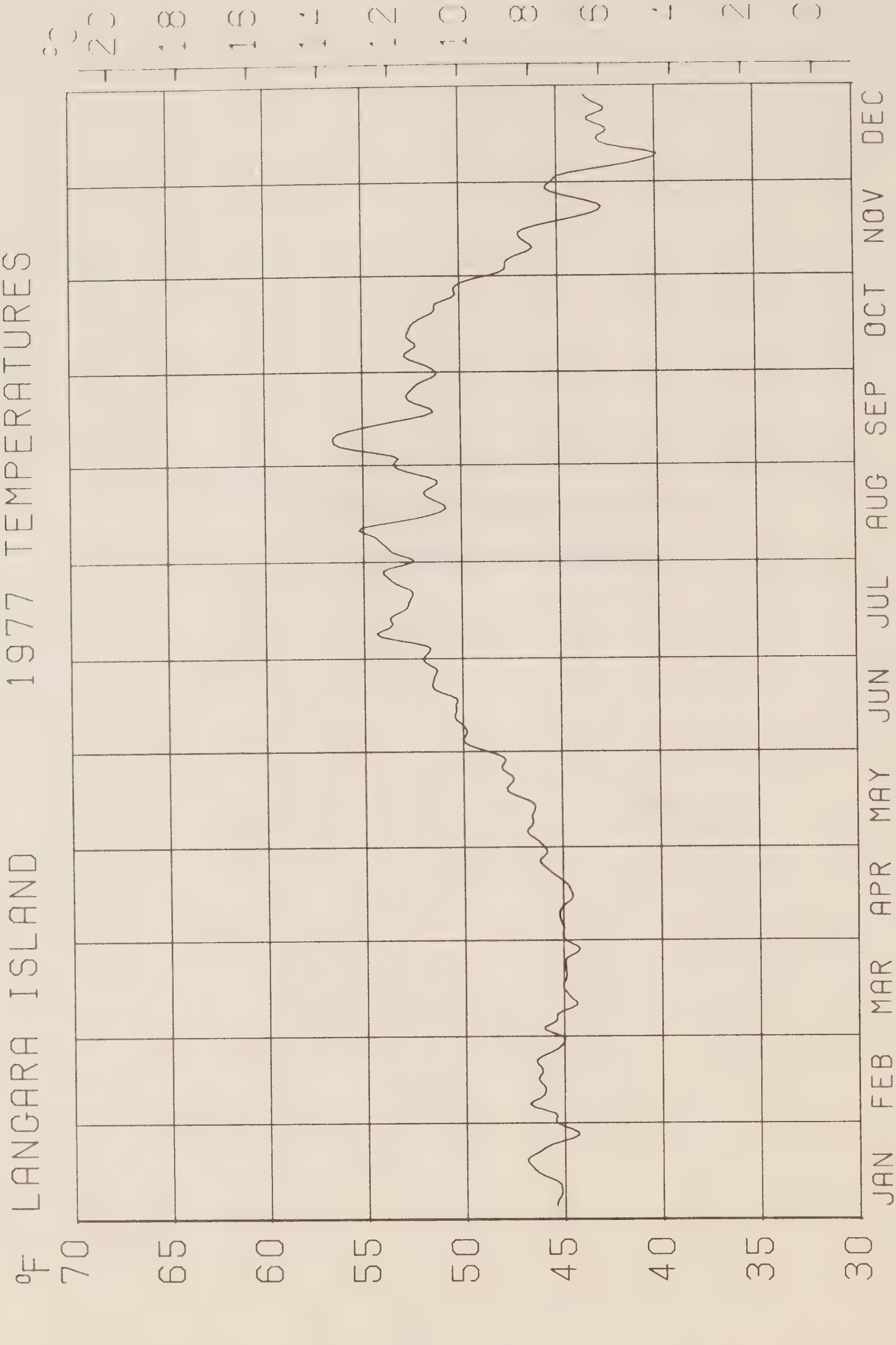
Normally-weighted Running Means

for Temperature and Salinity

1977

TEMP: Temperature (°F)

SAL: Salinity (°/₀₀)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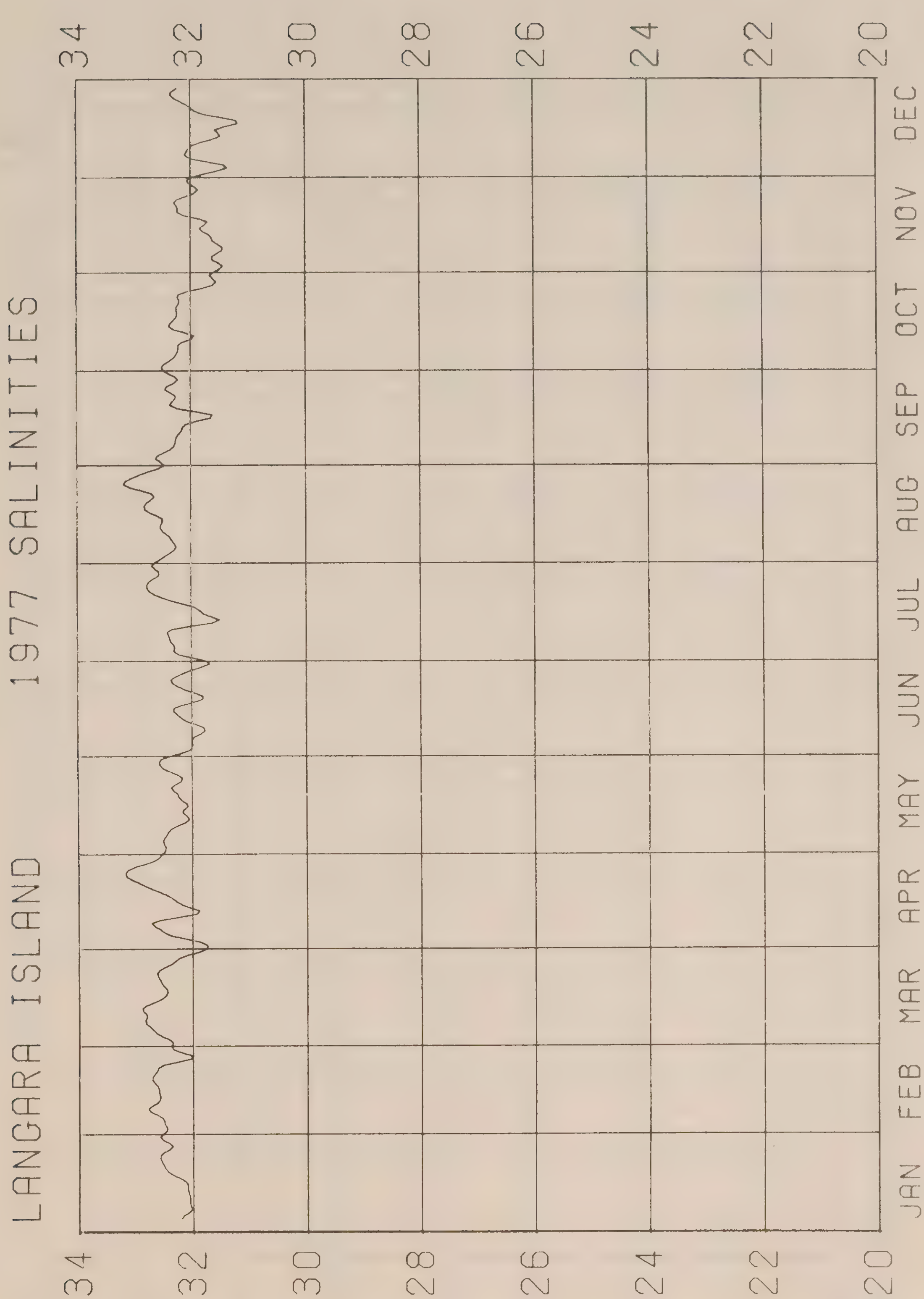
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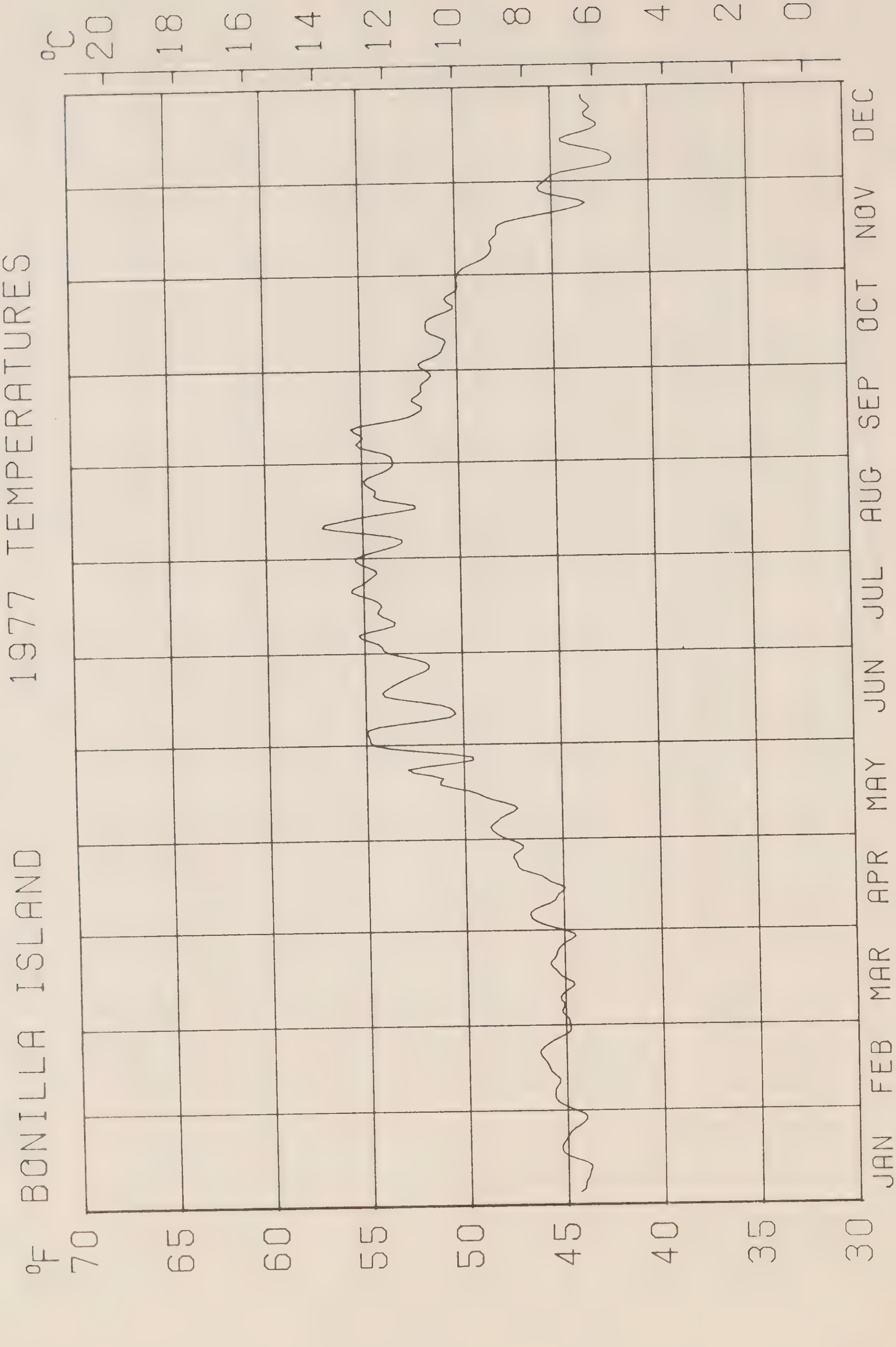
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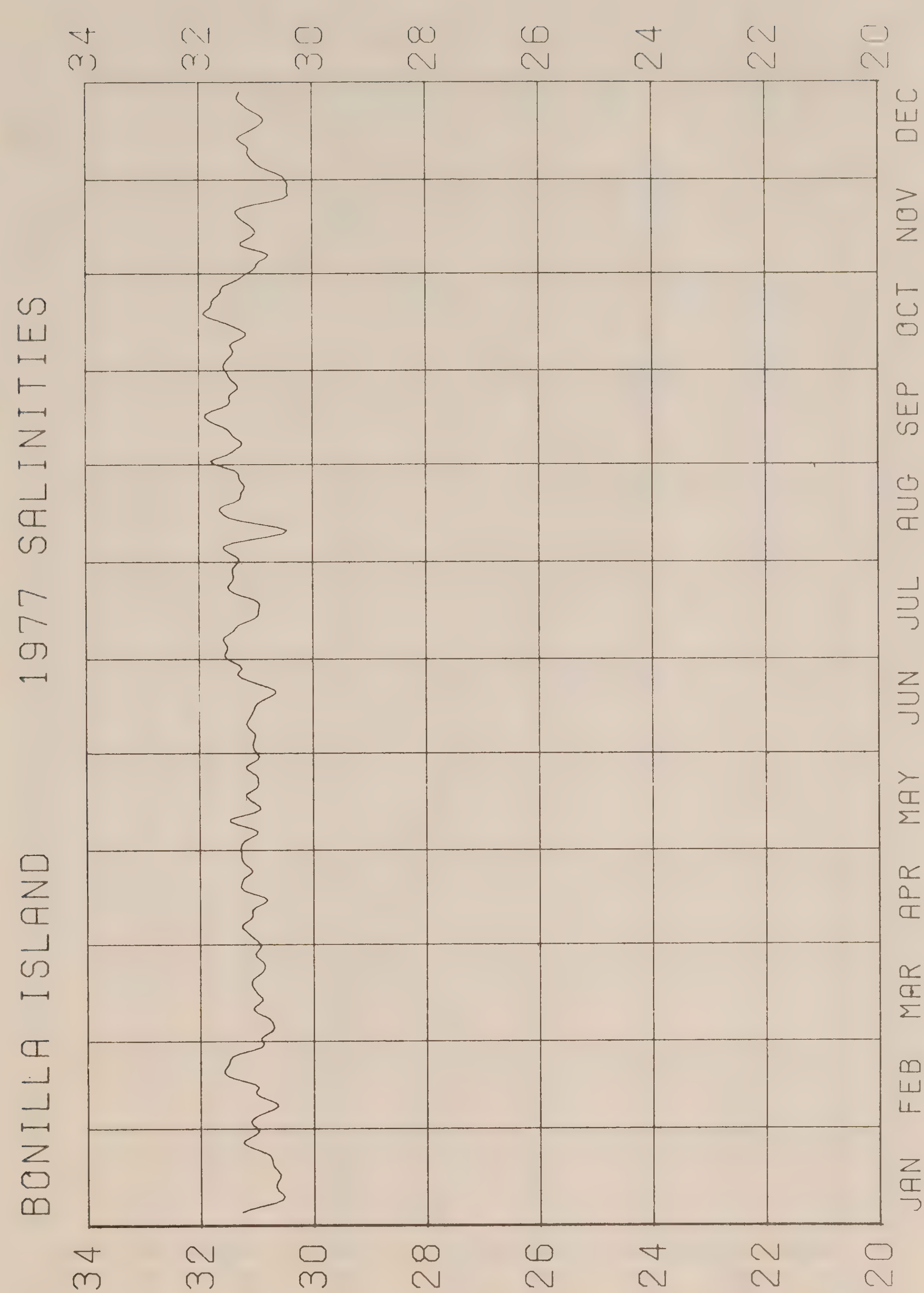
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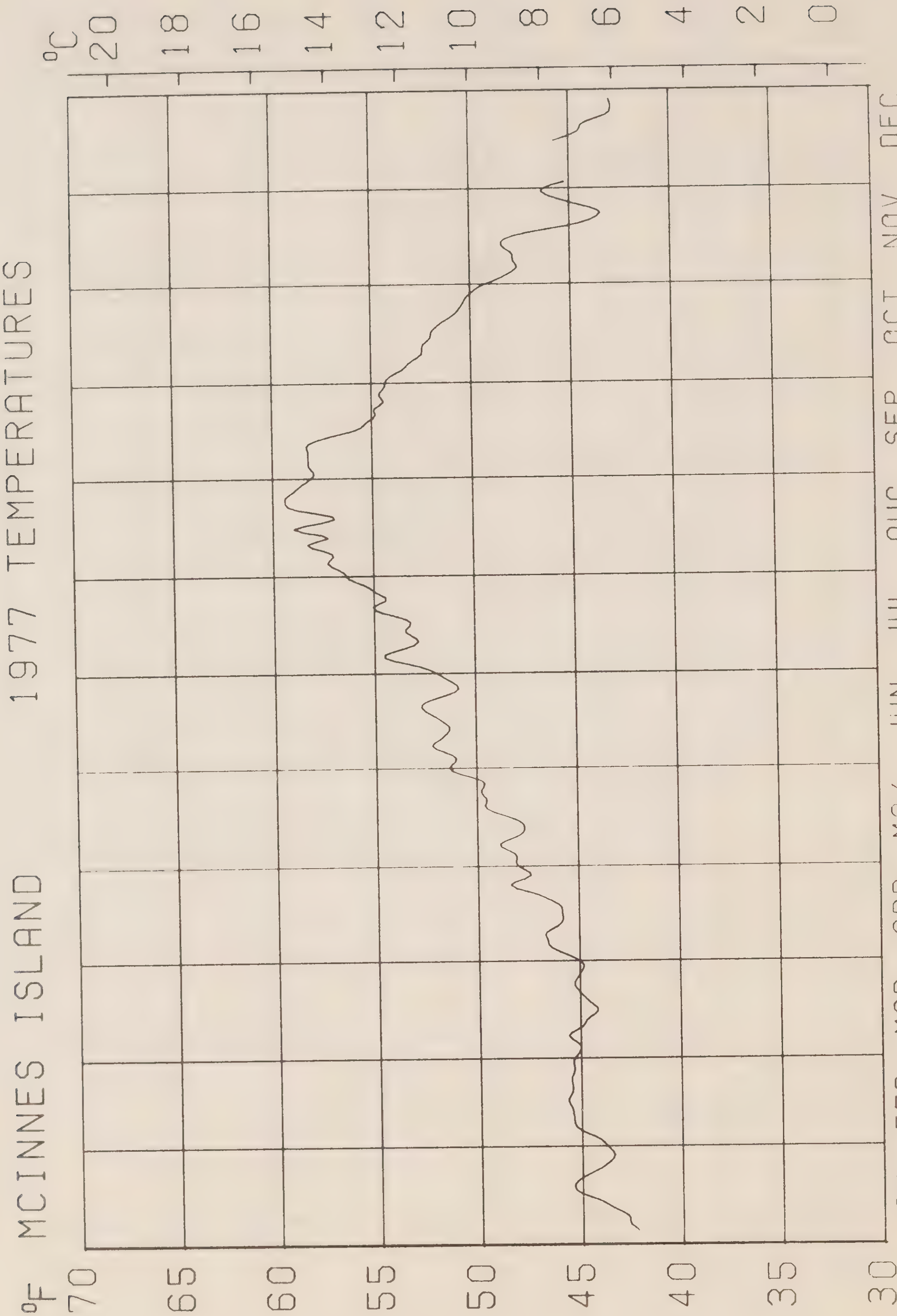
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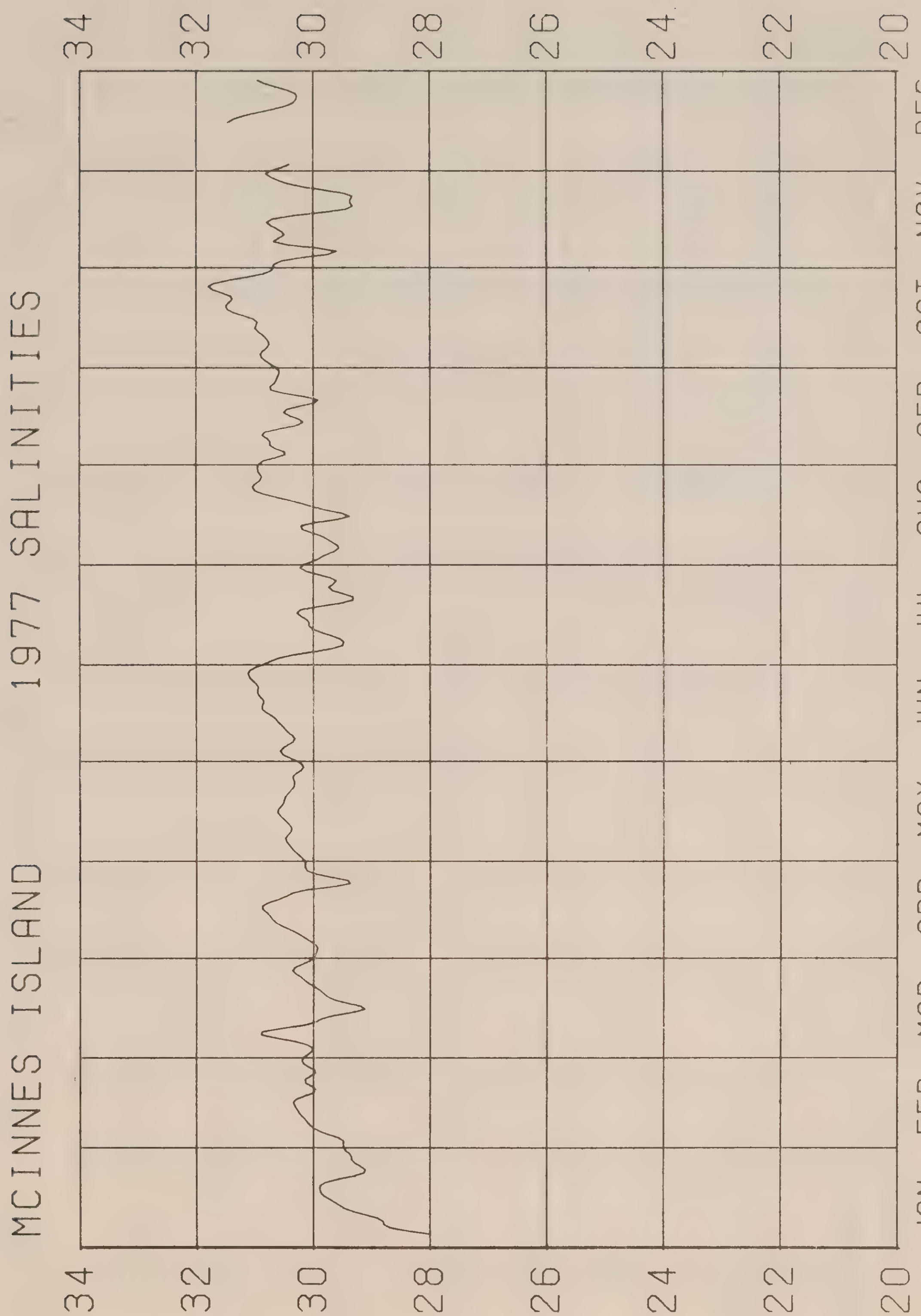
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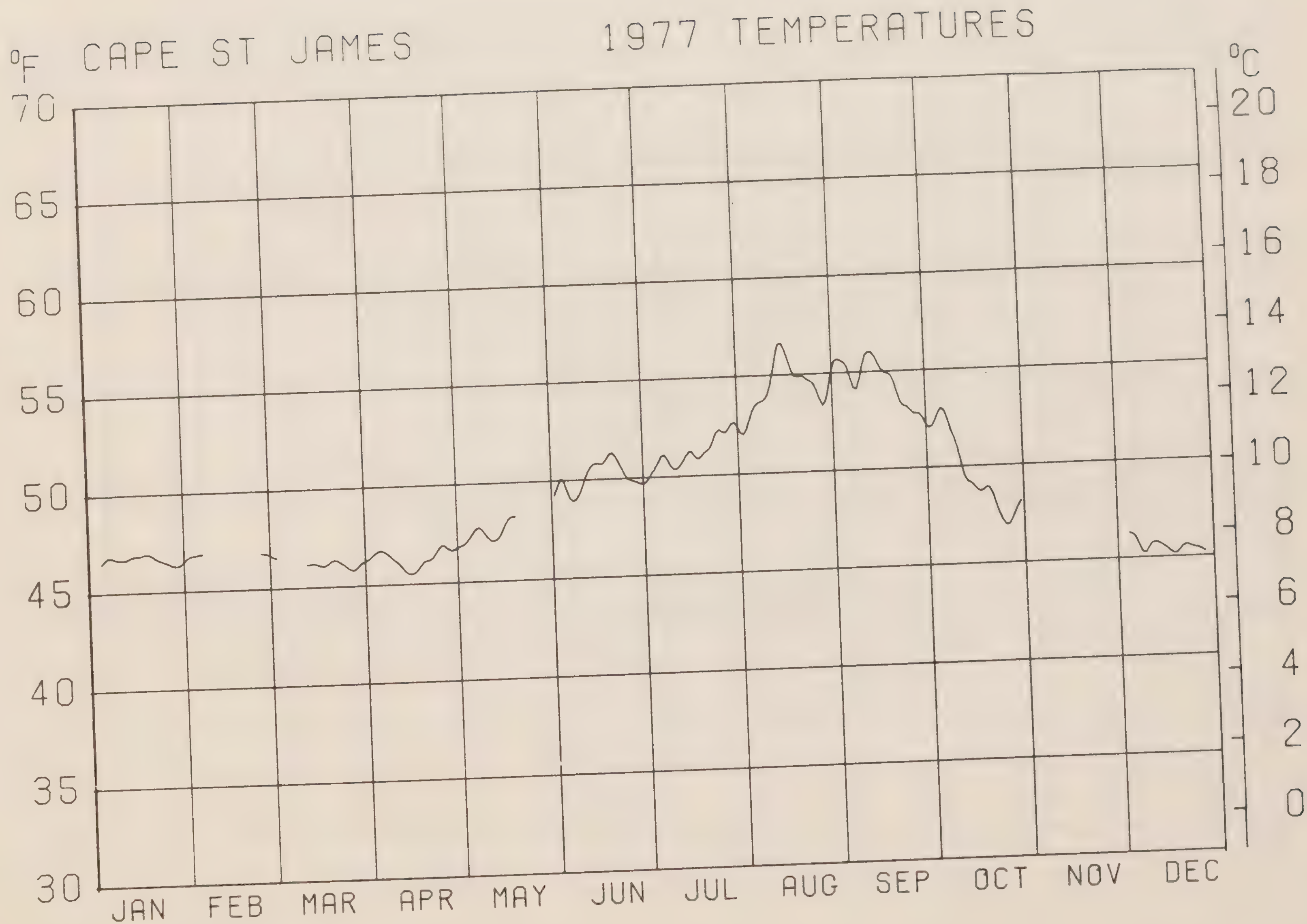
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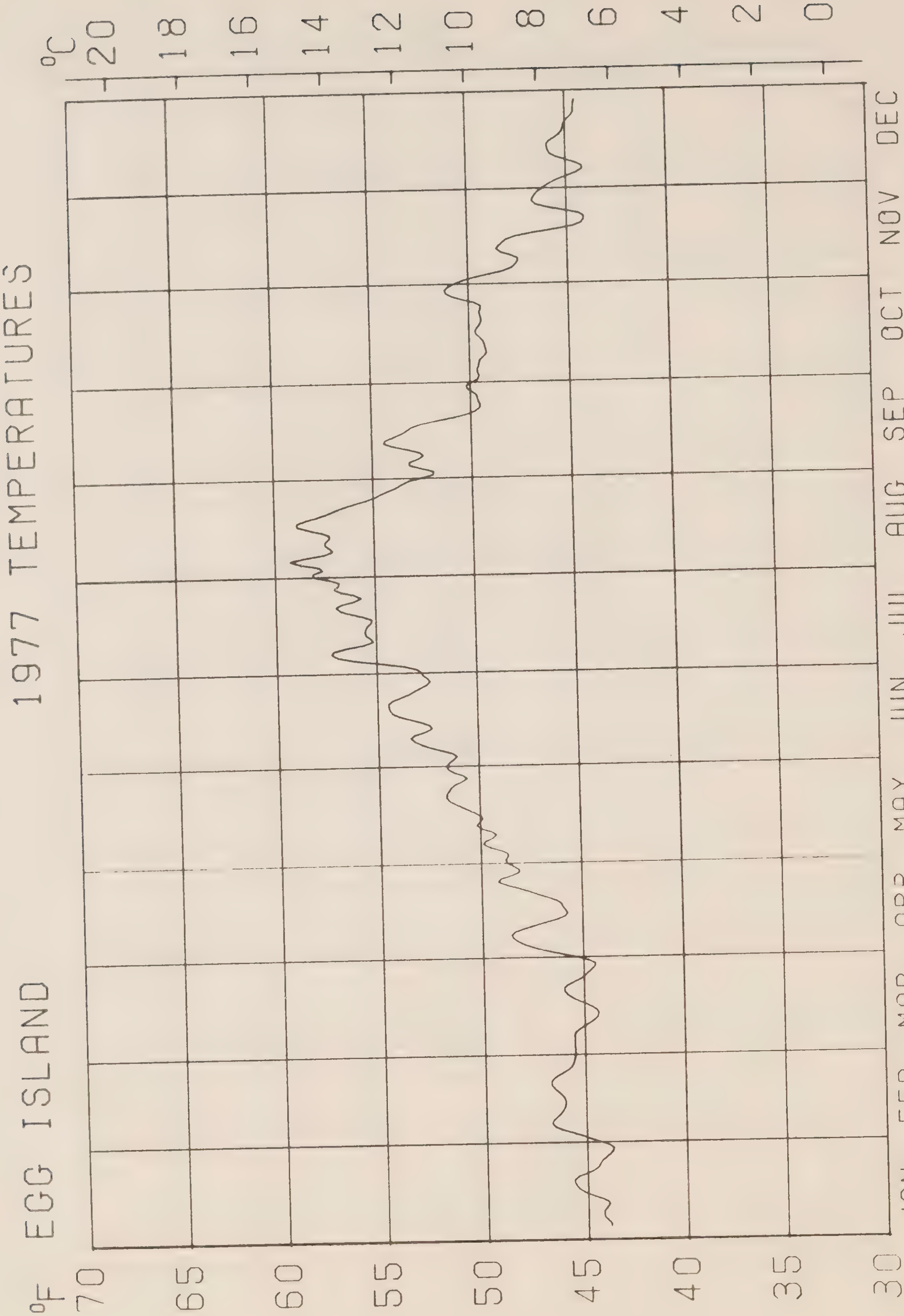
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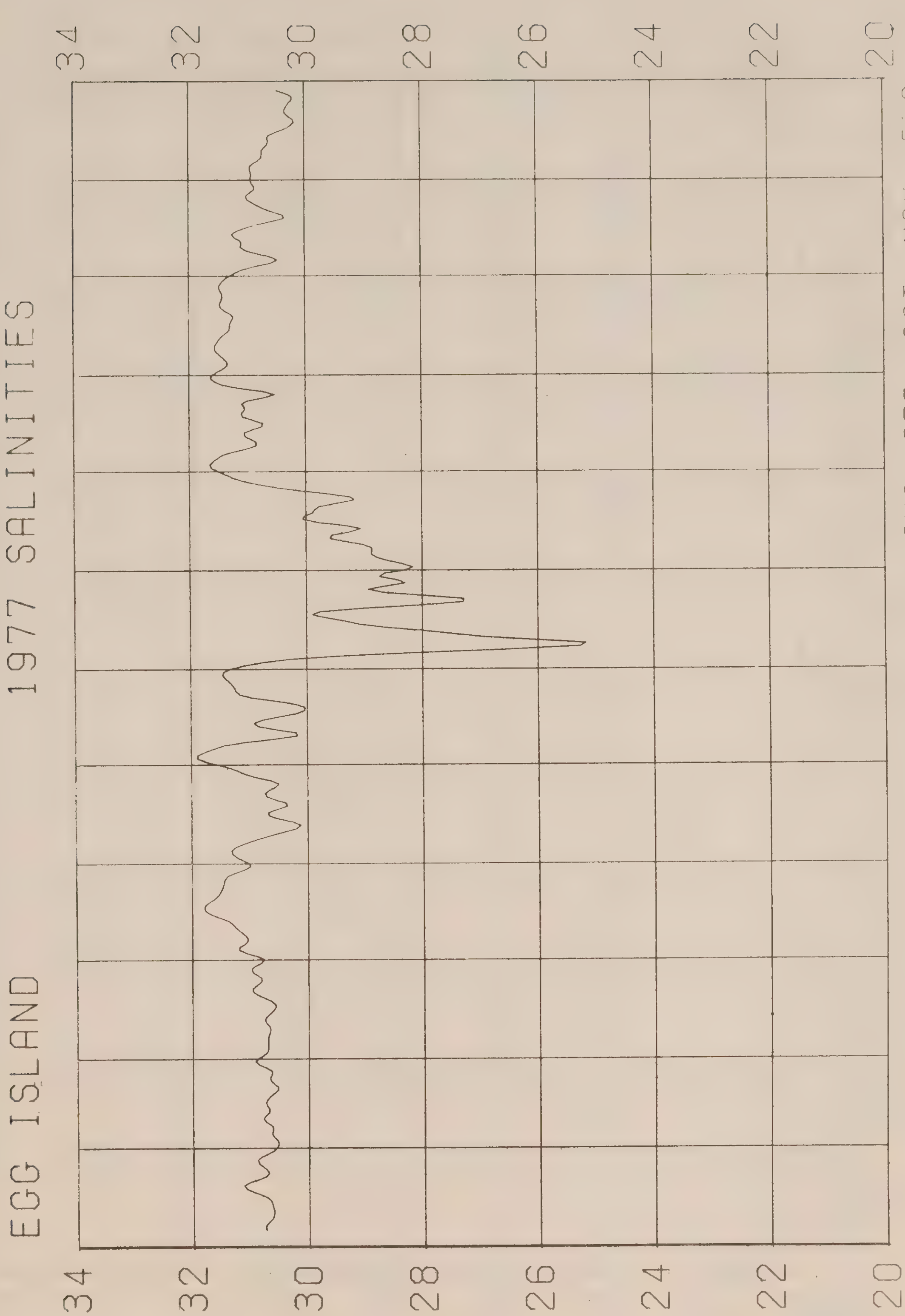
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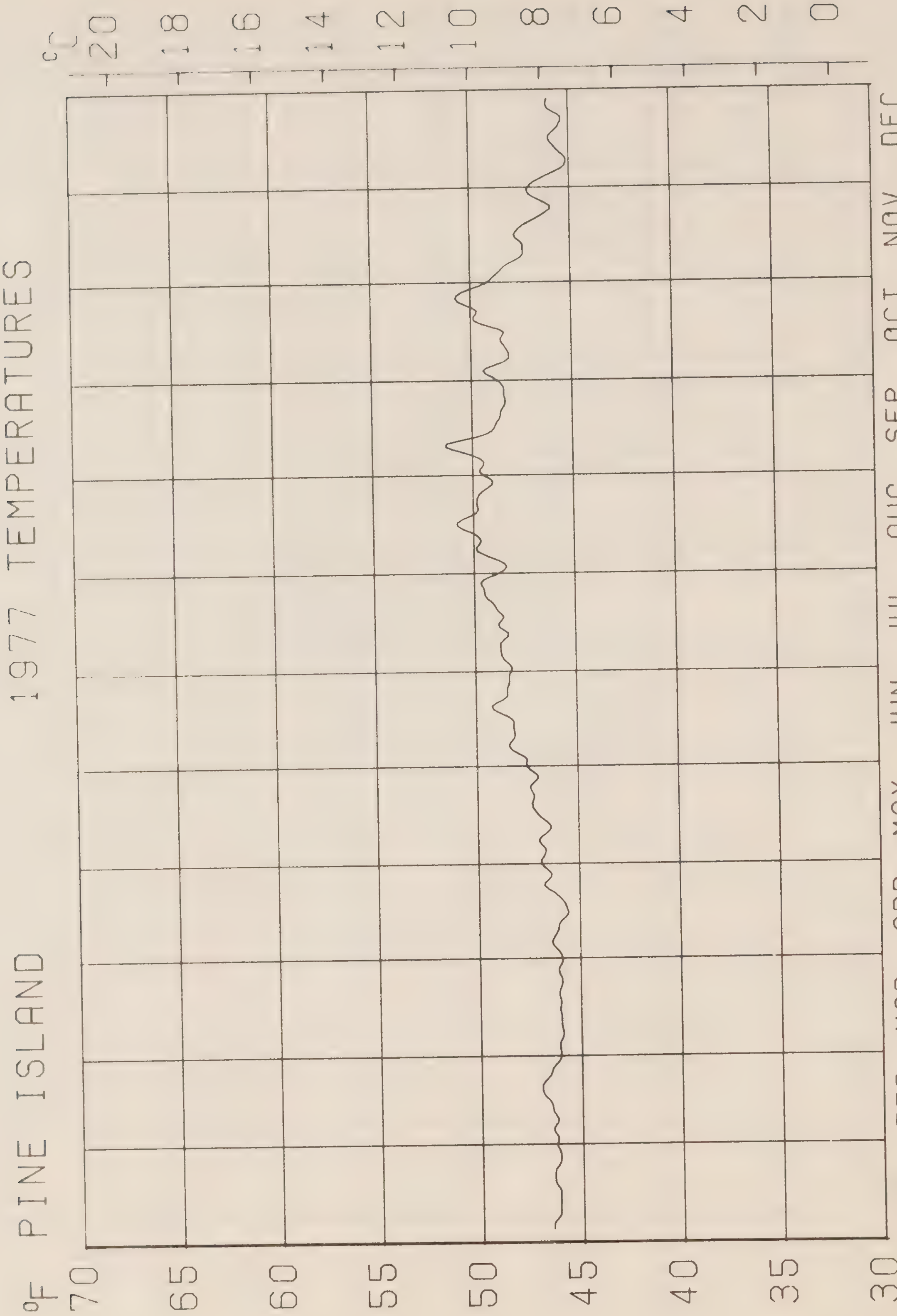
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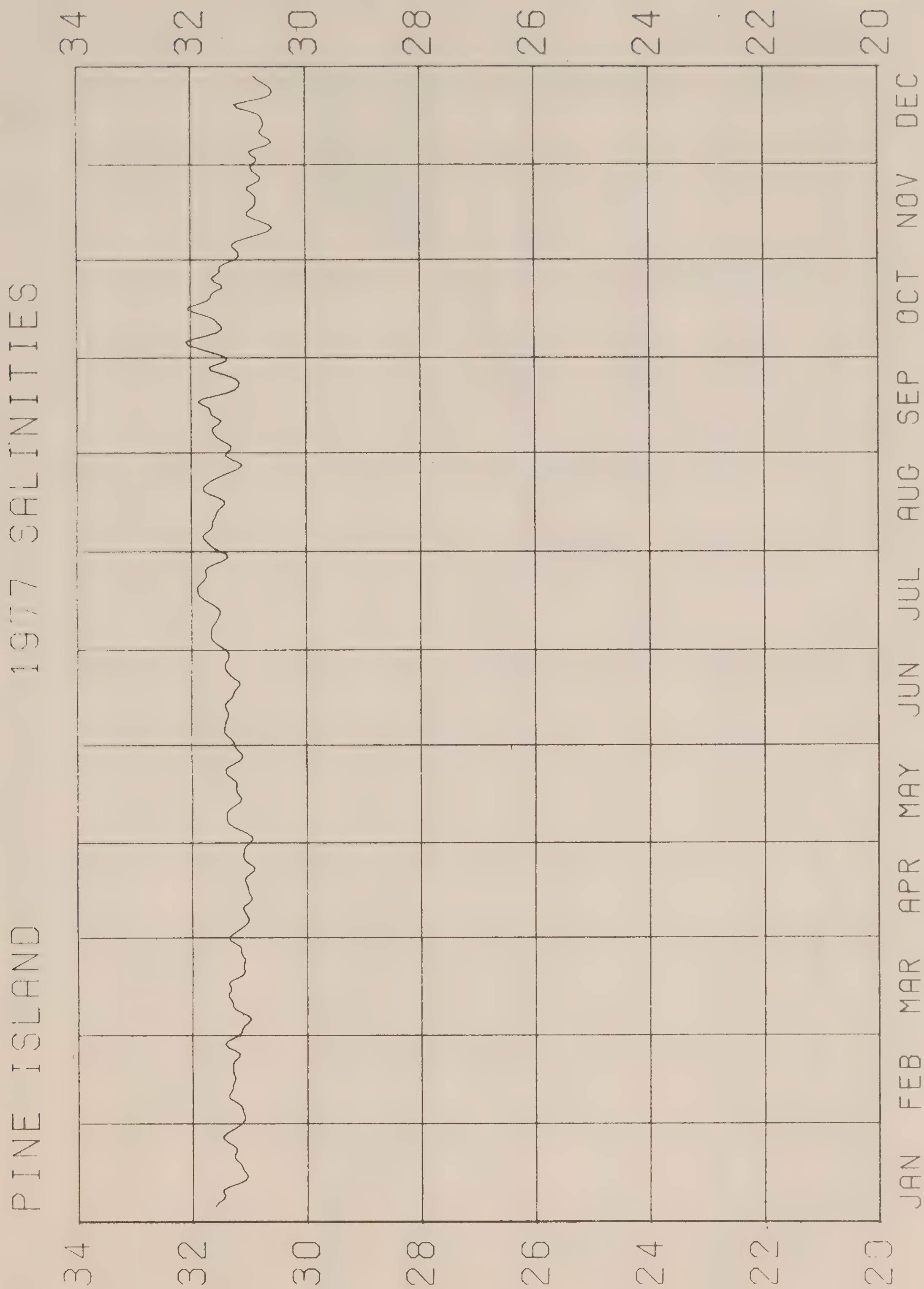
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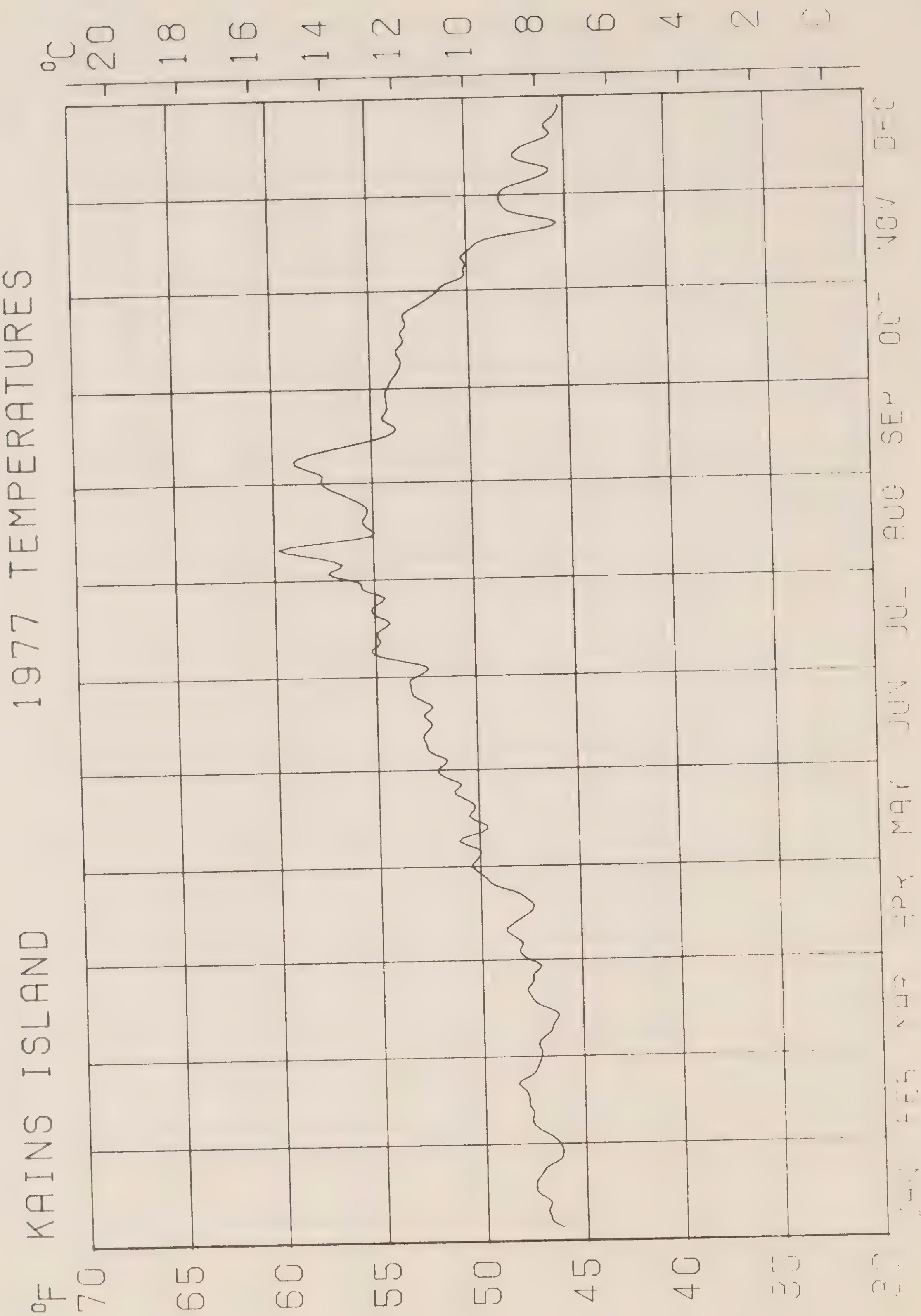
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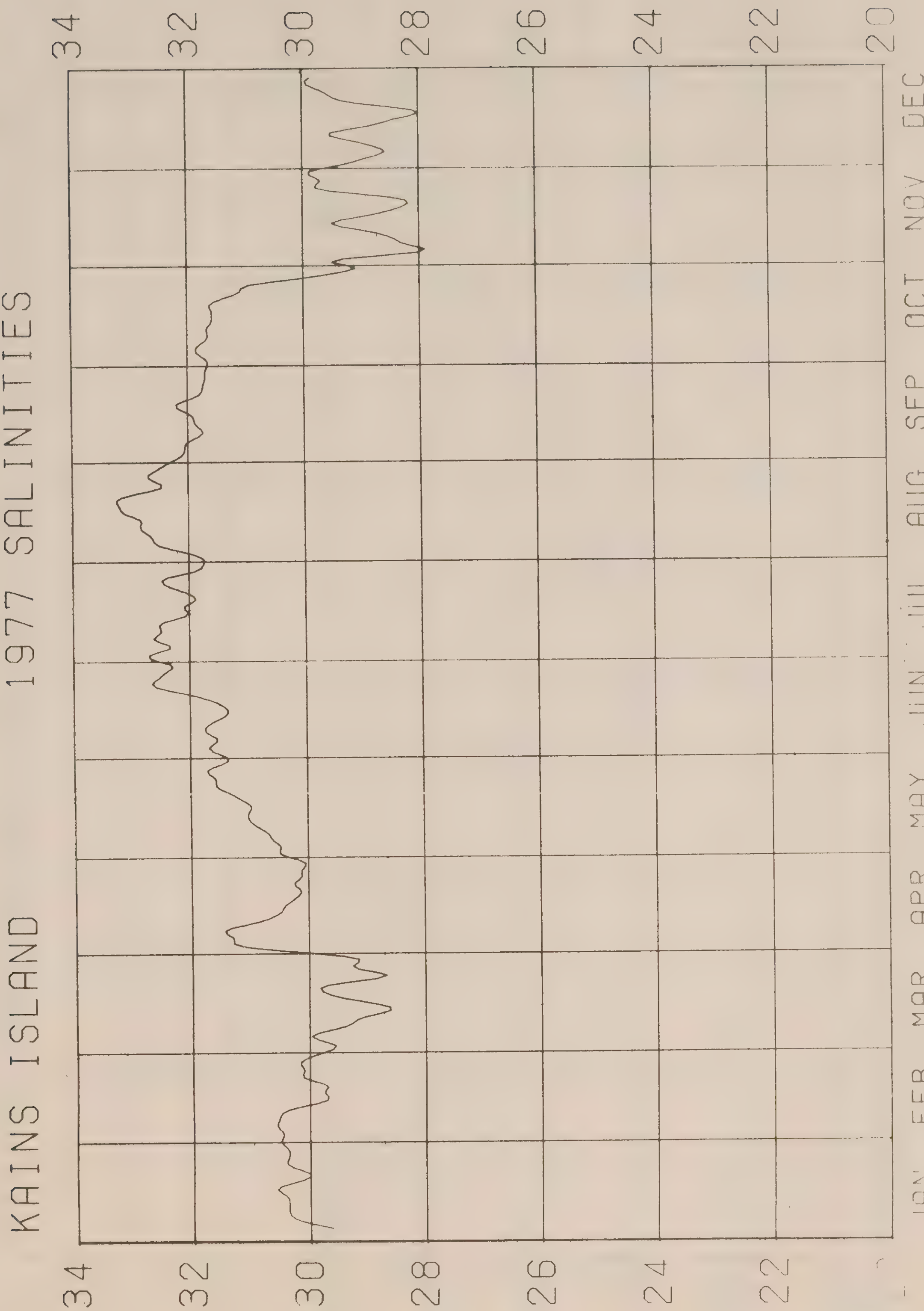
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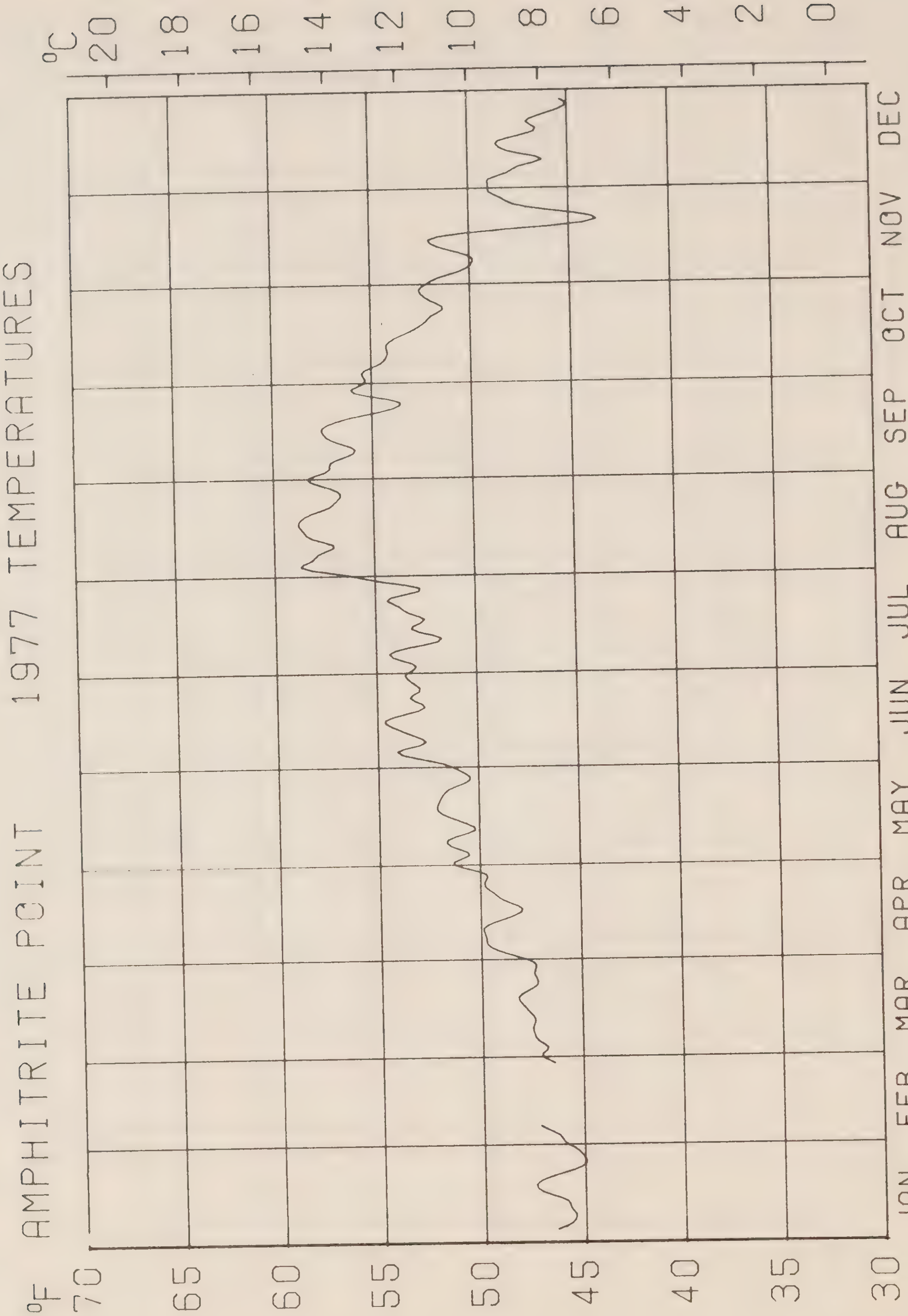
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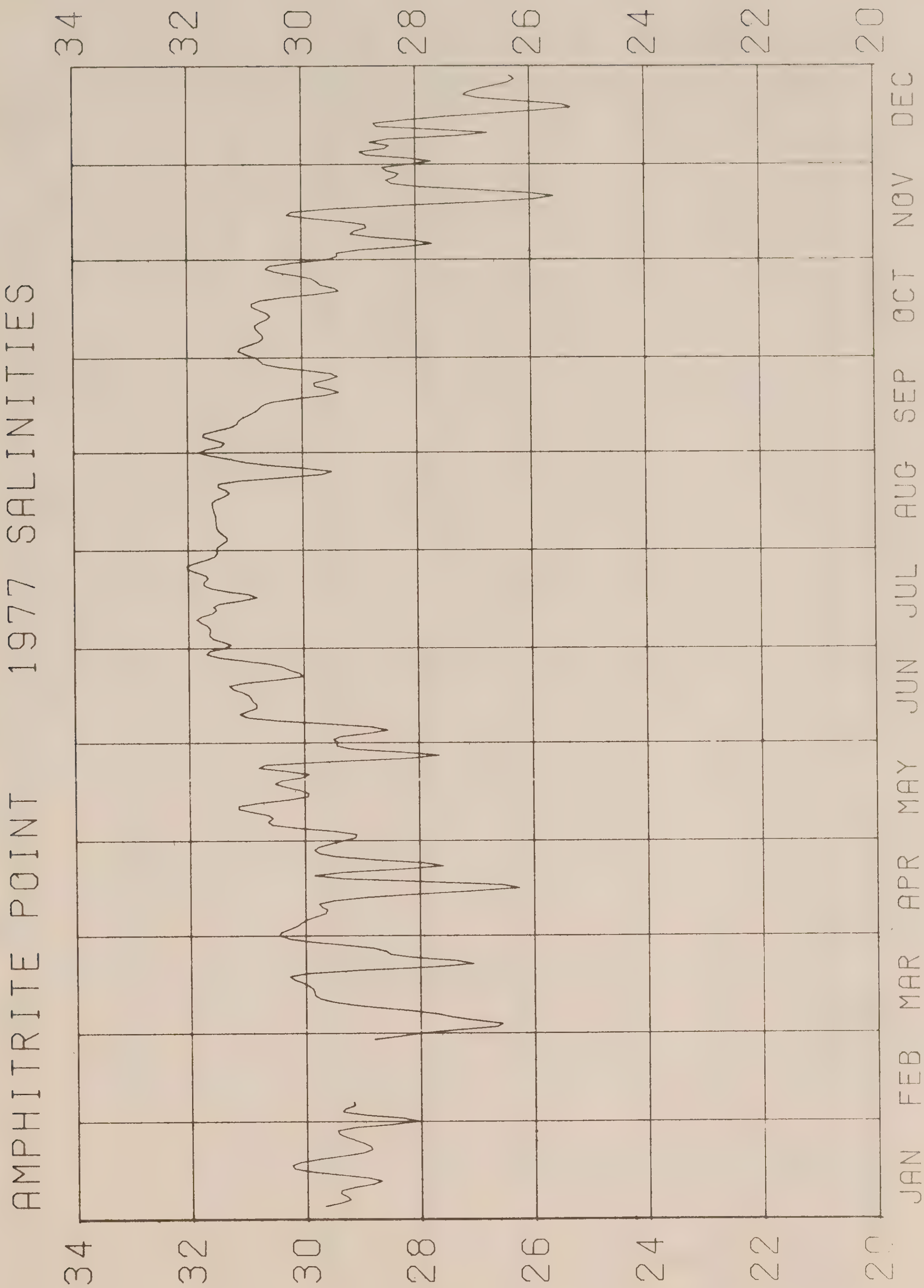
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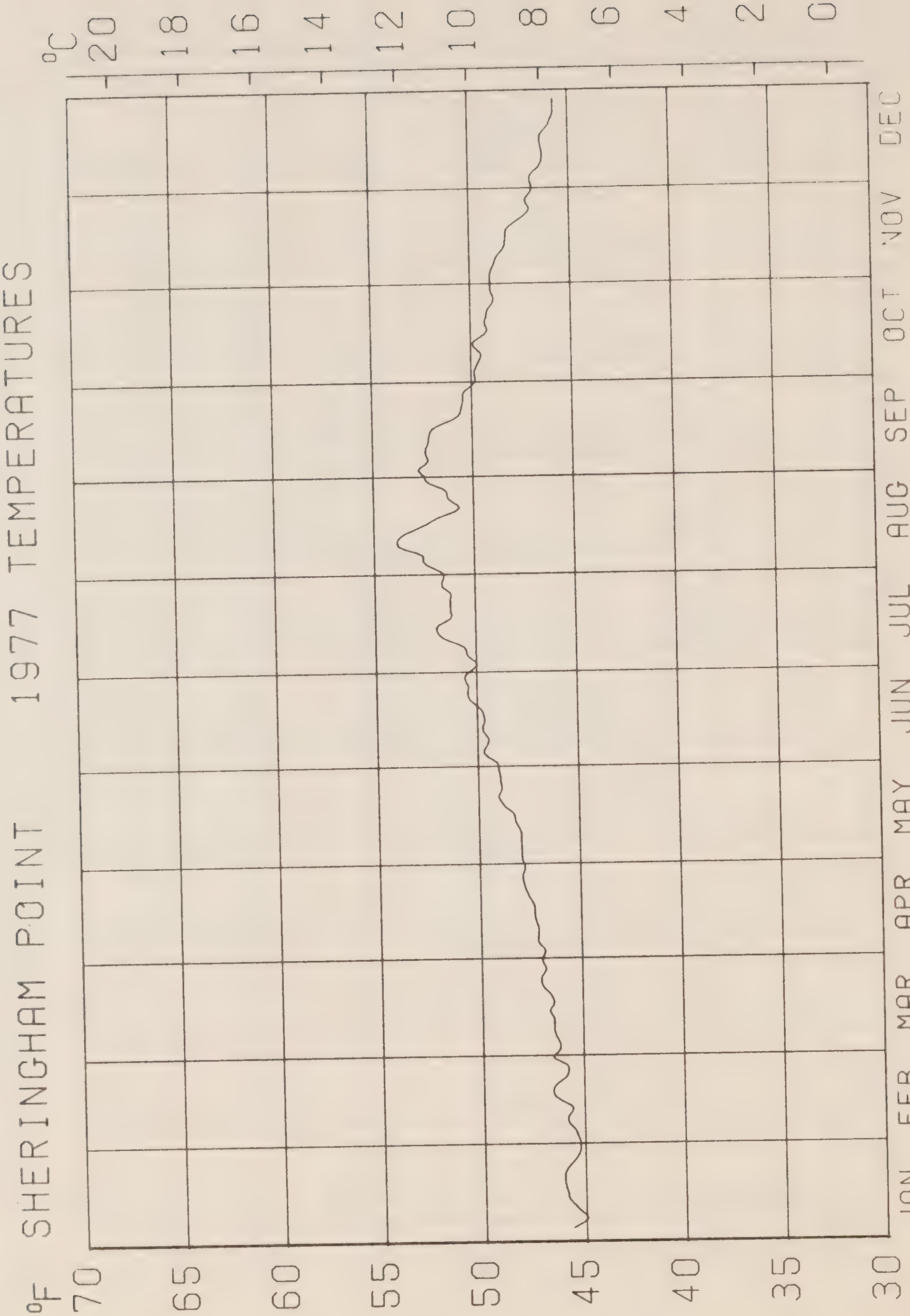
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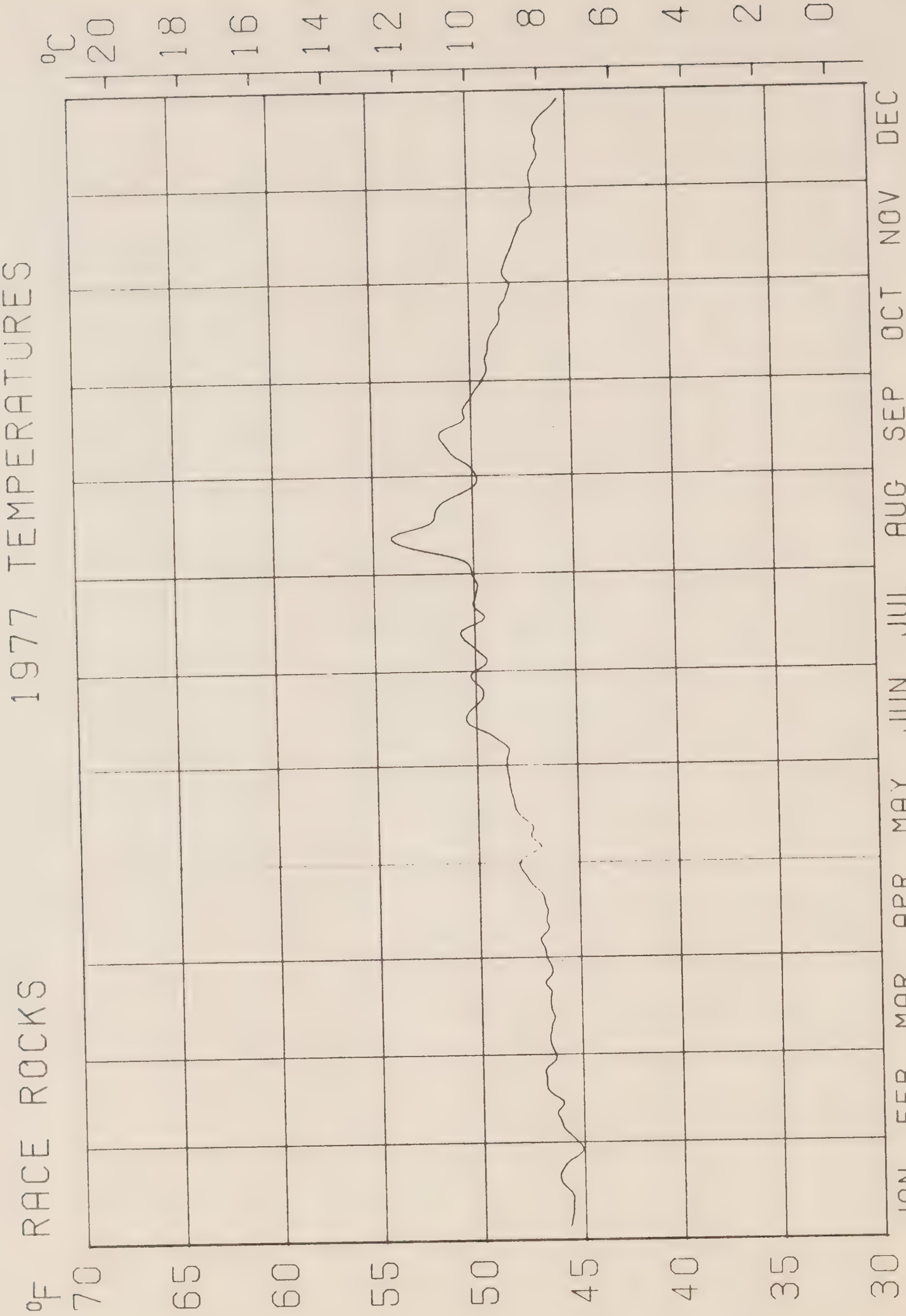
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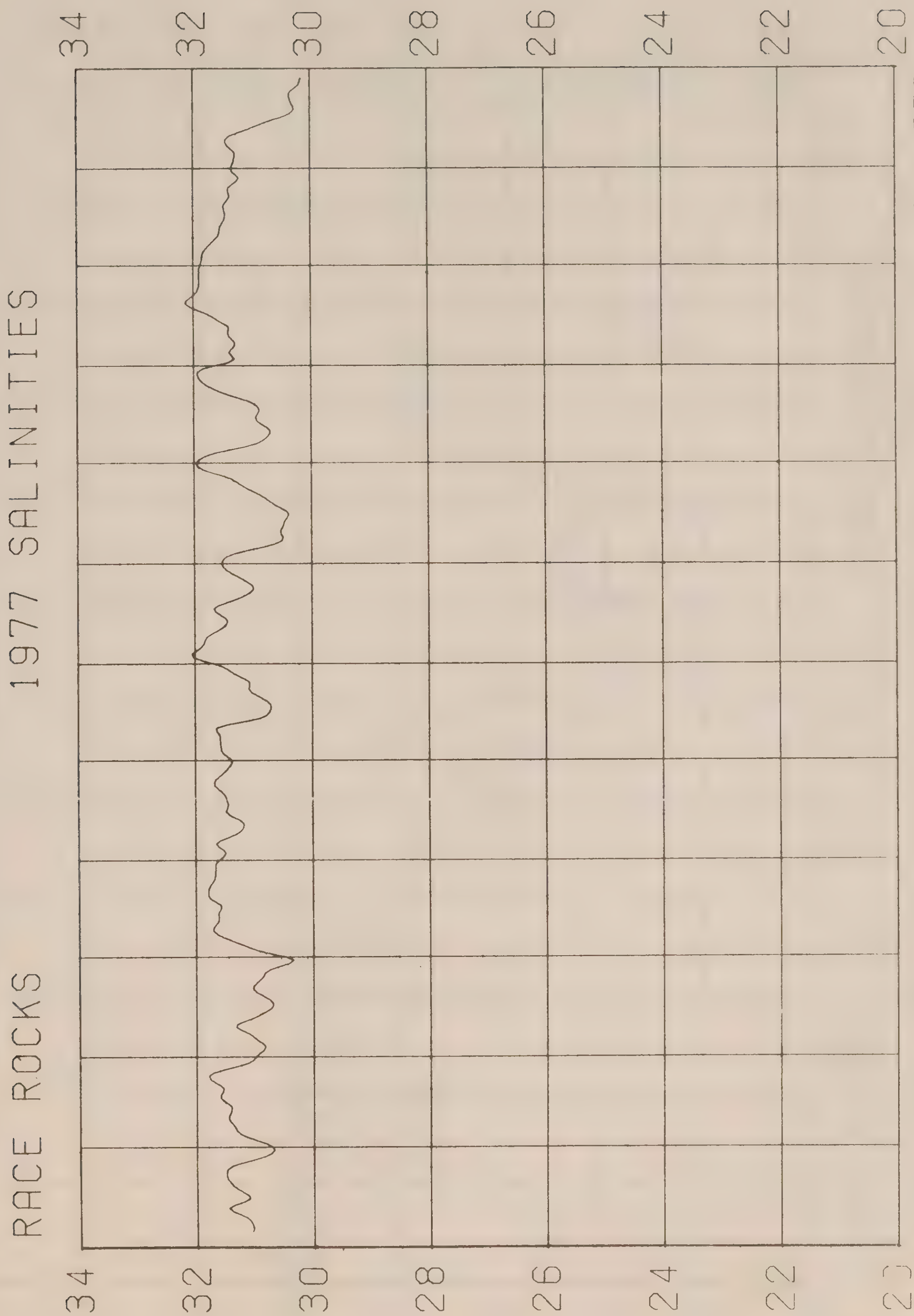
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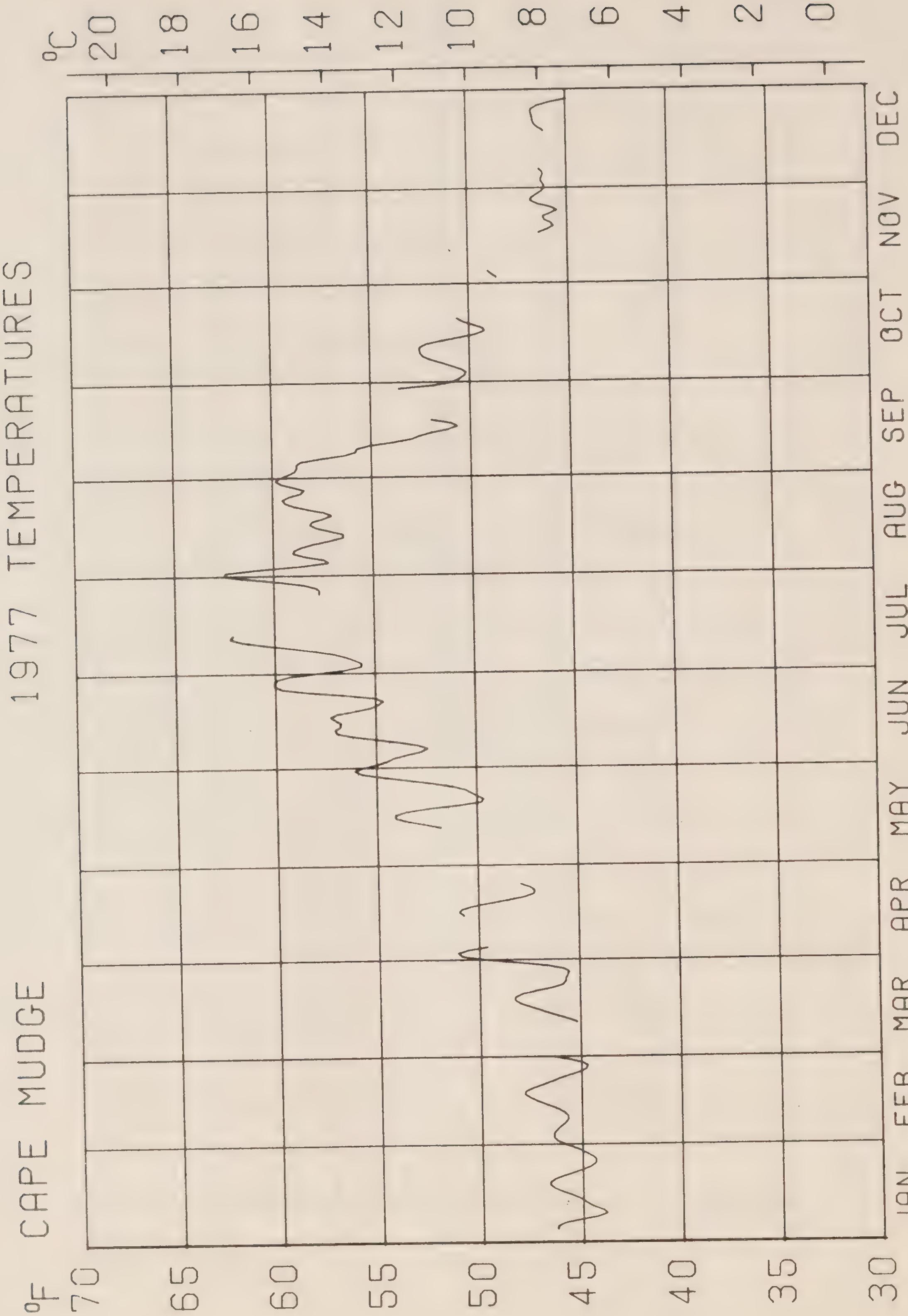
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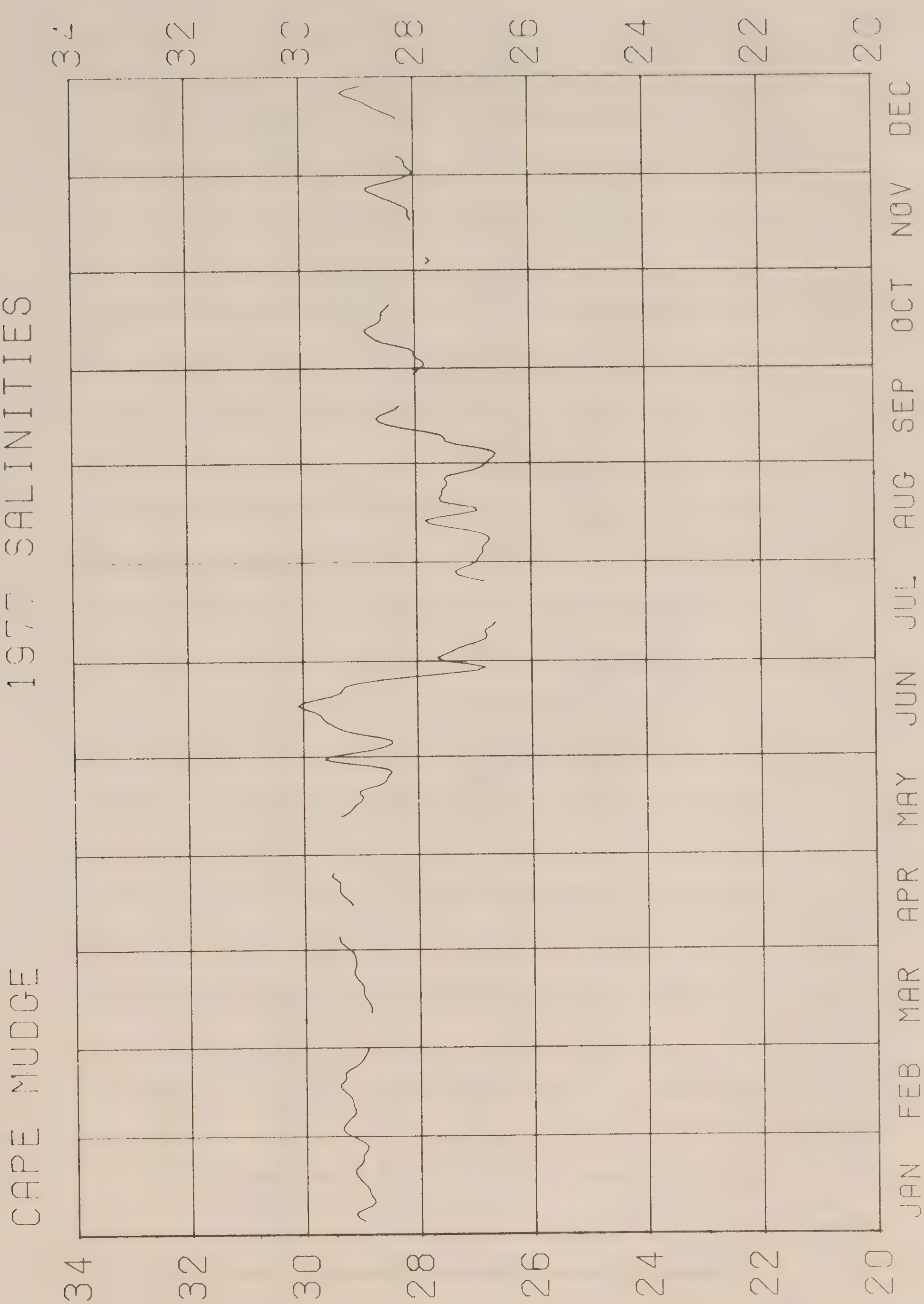
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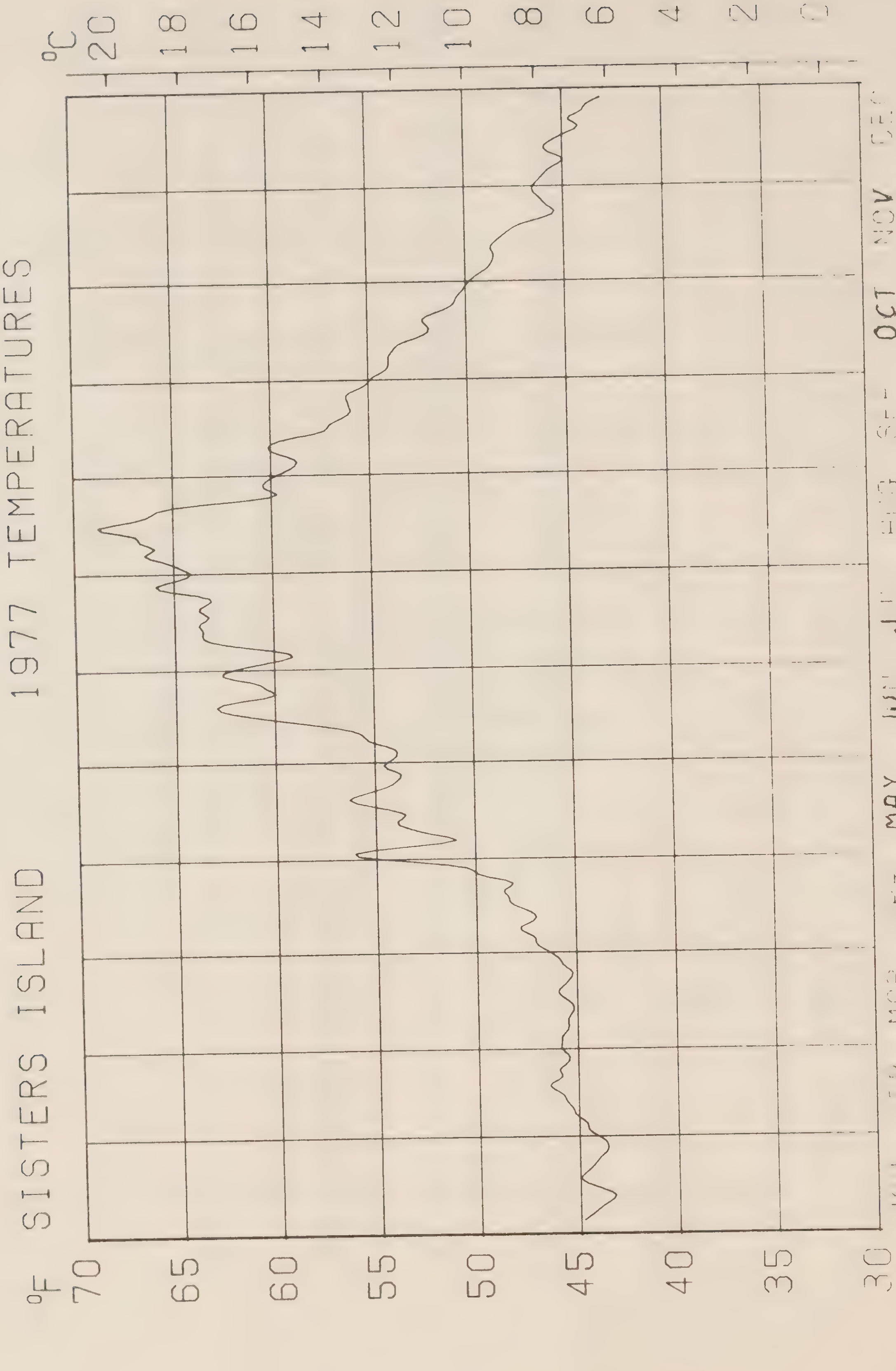
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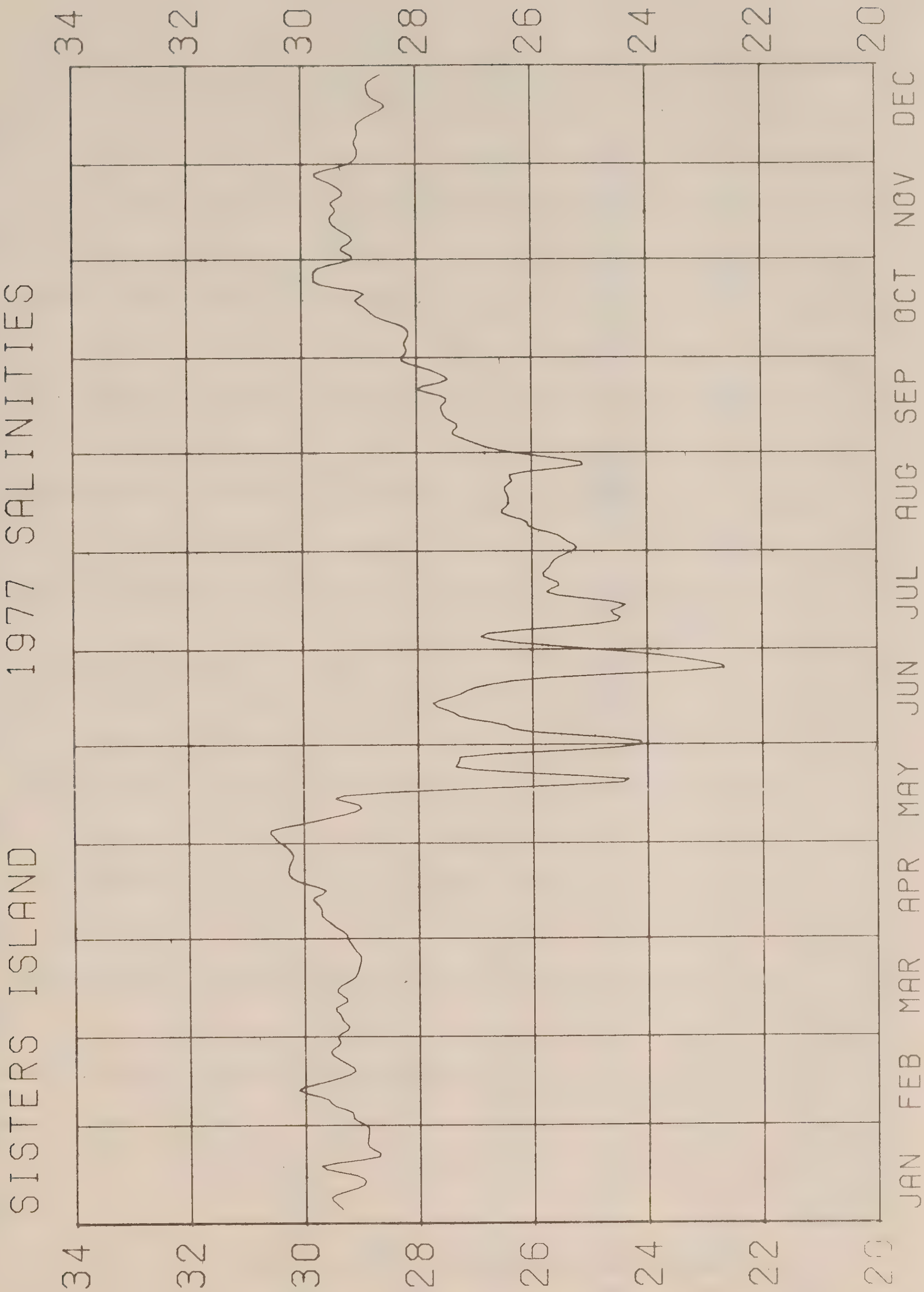
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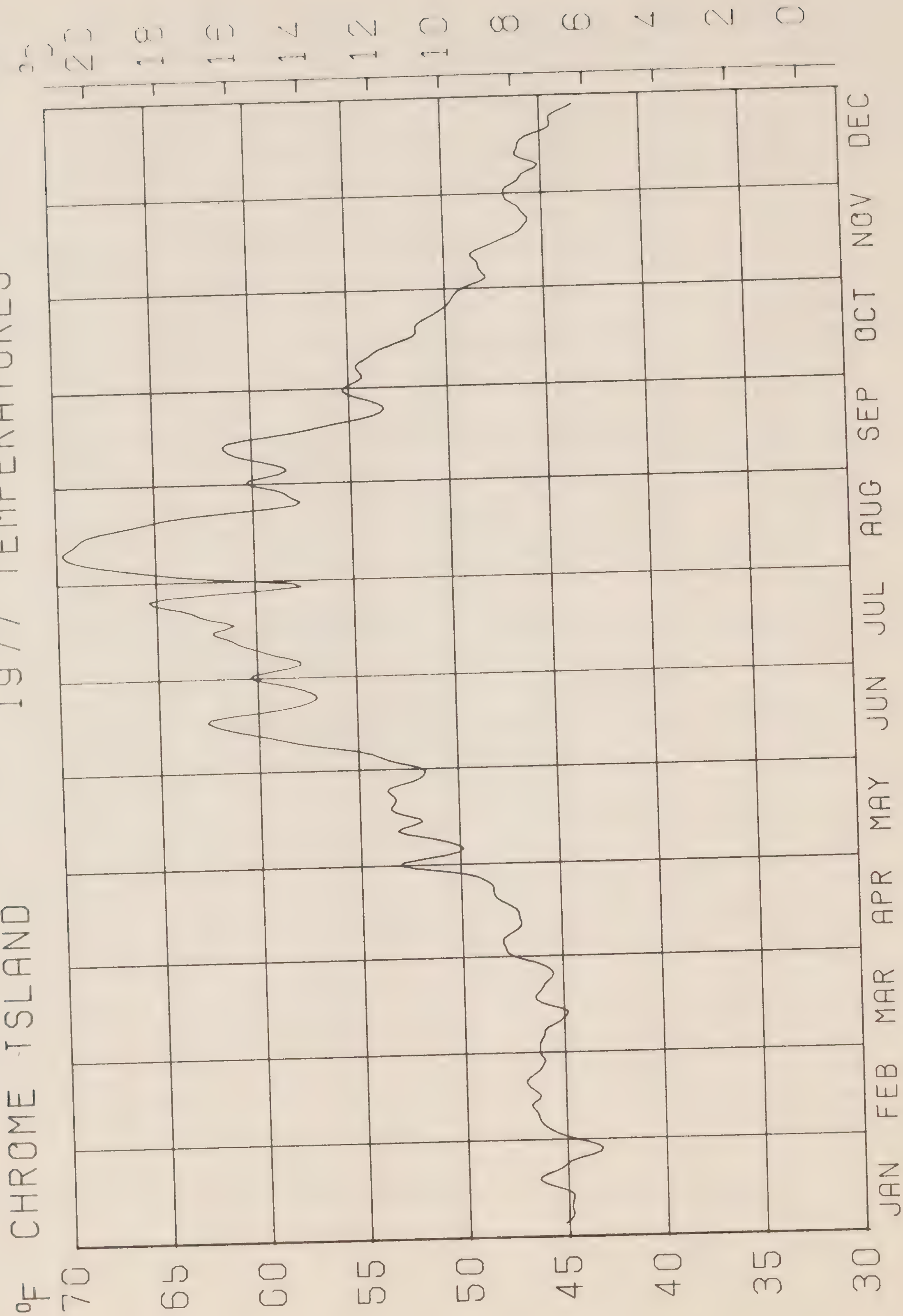
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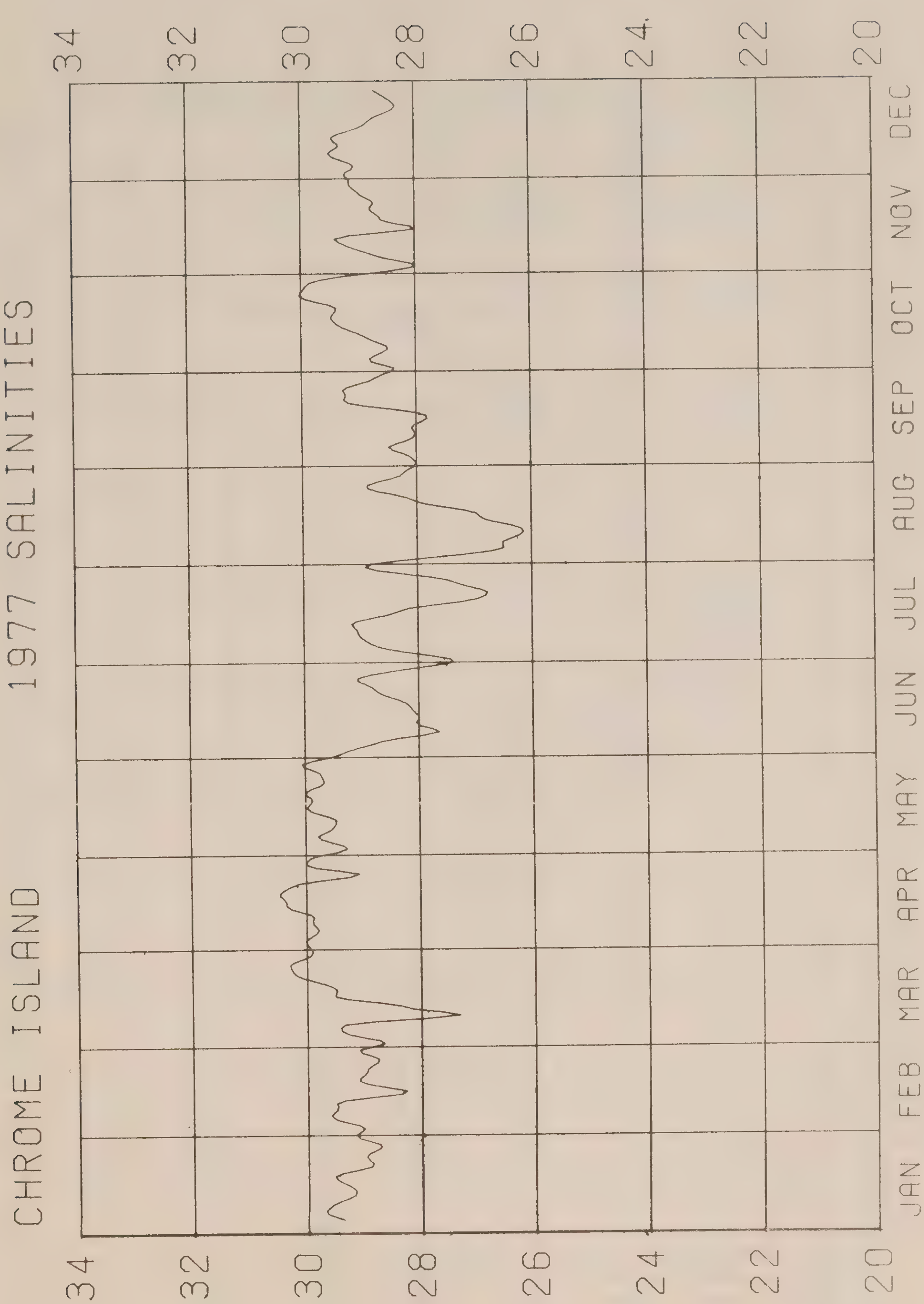
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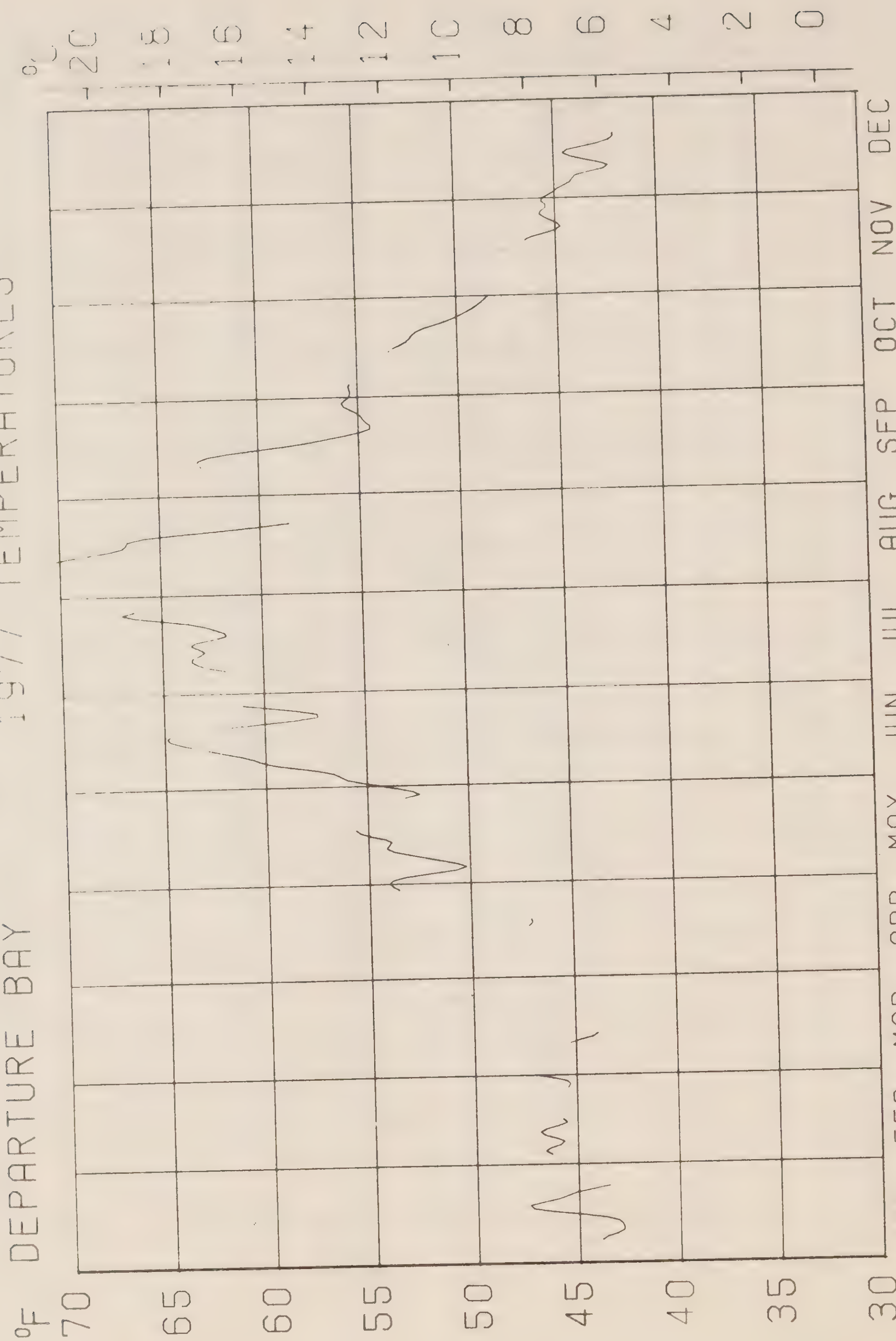
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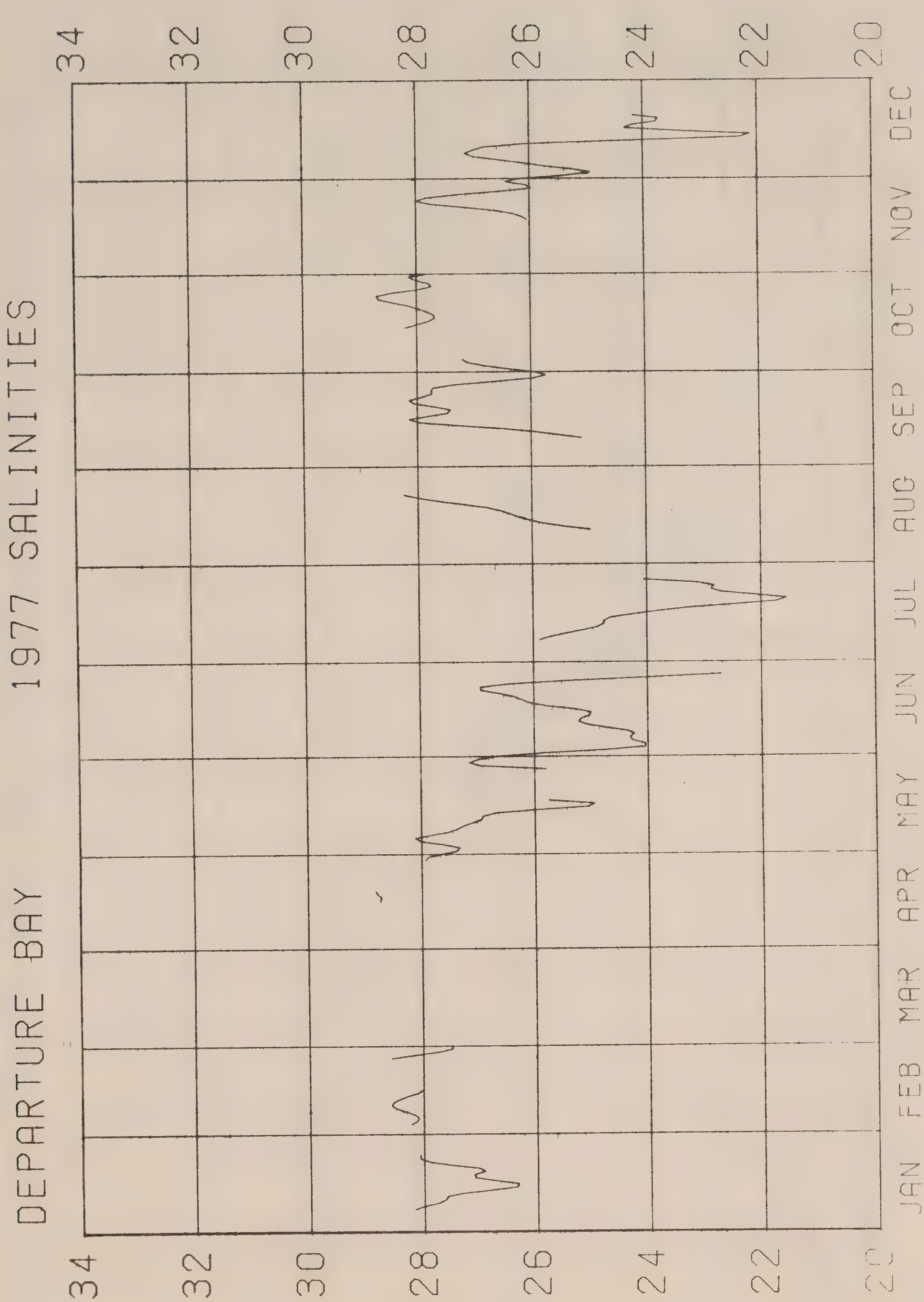
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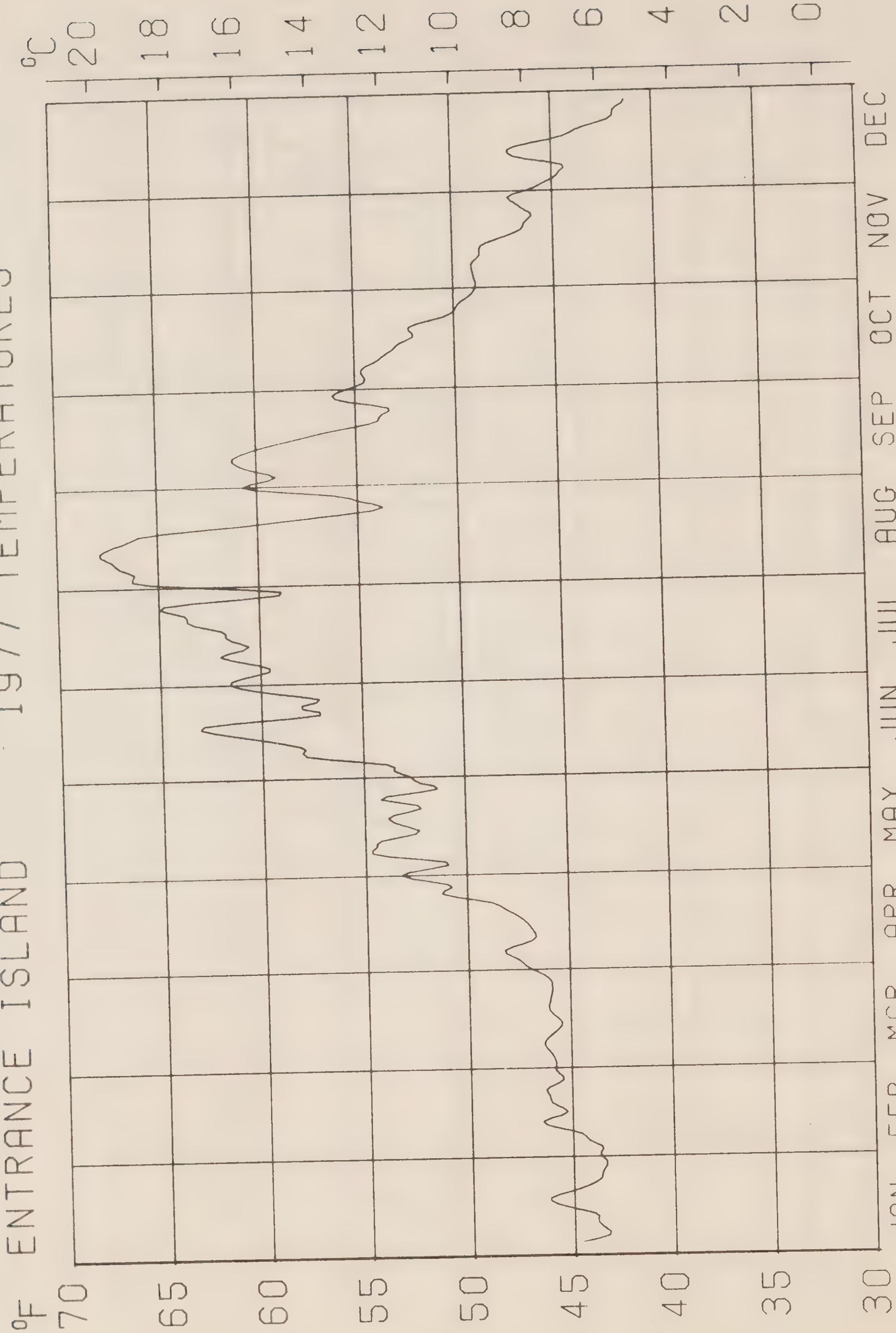
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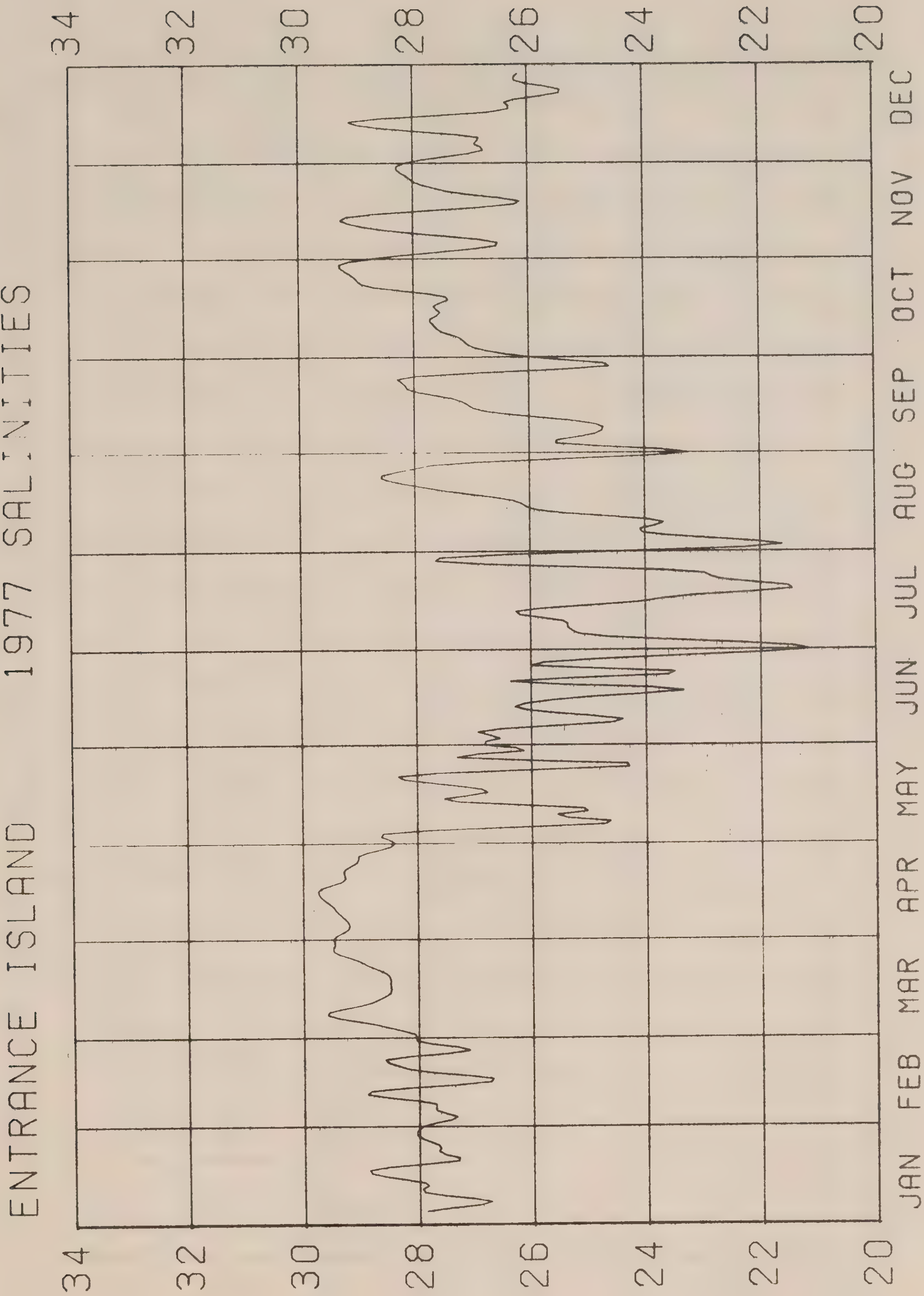

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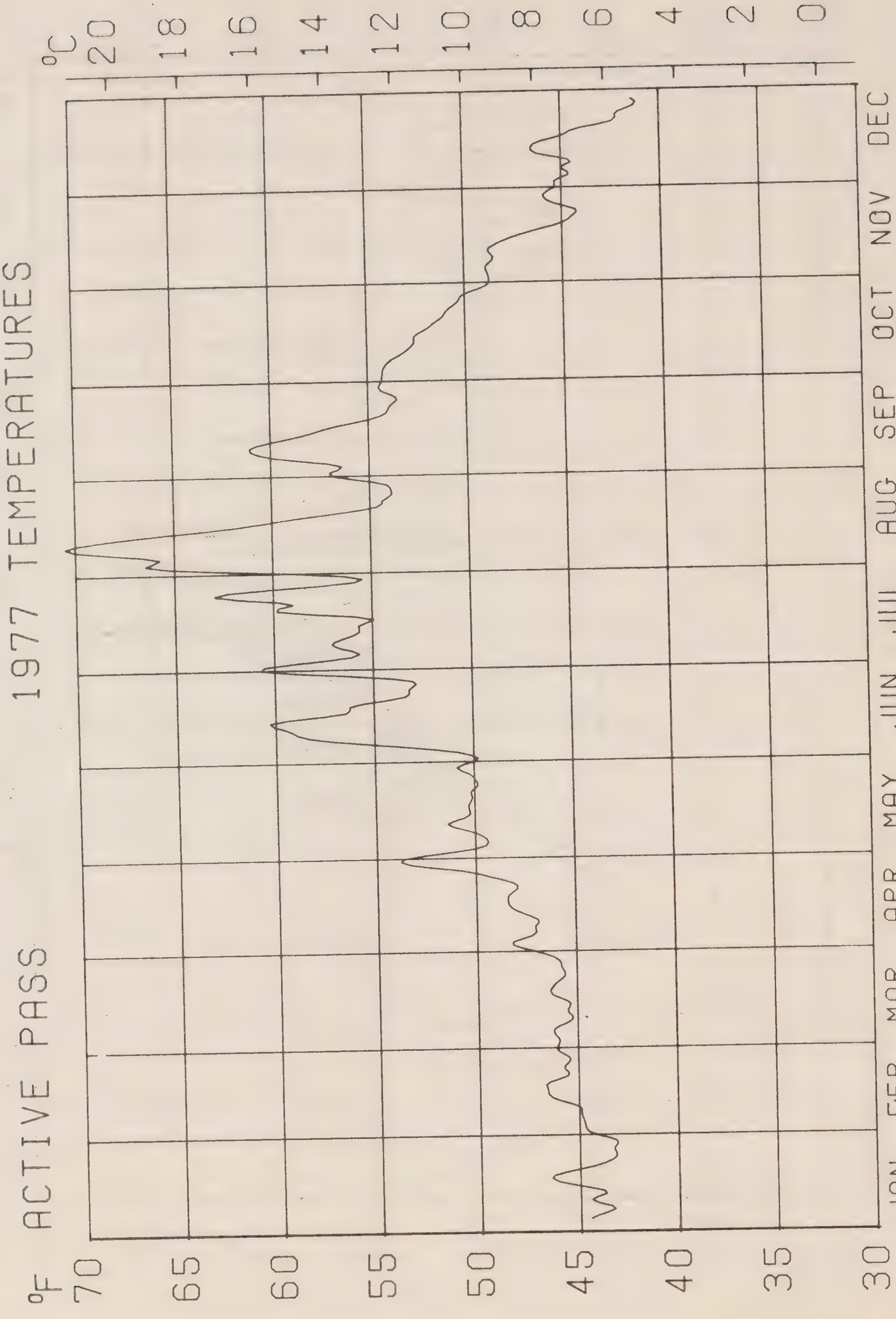
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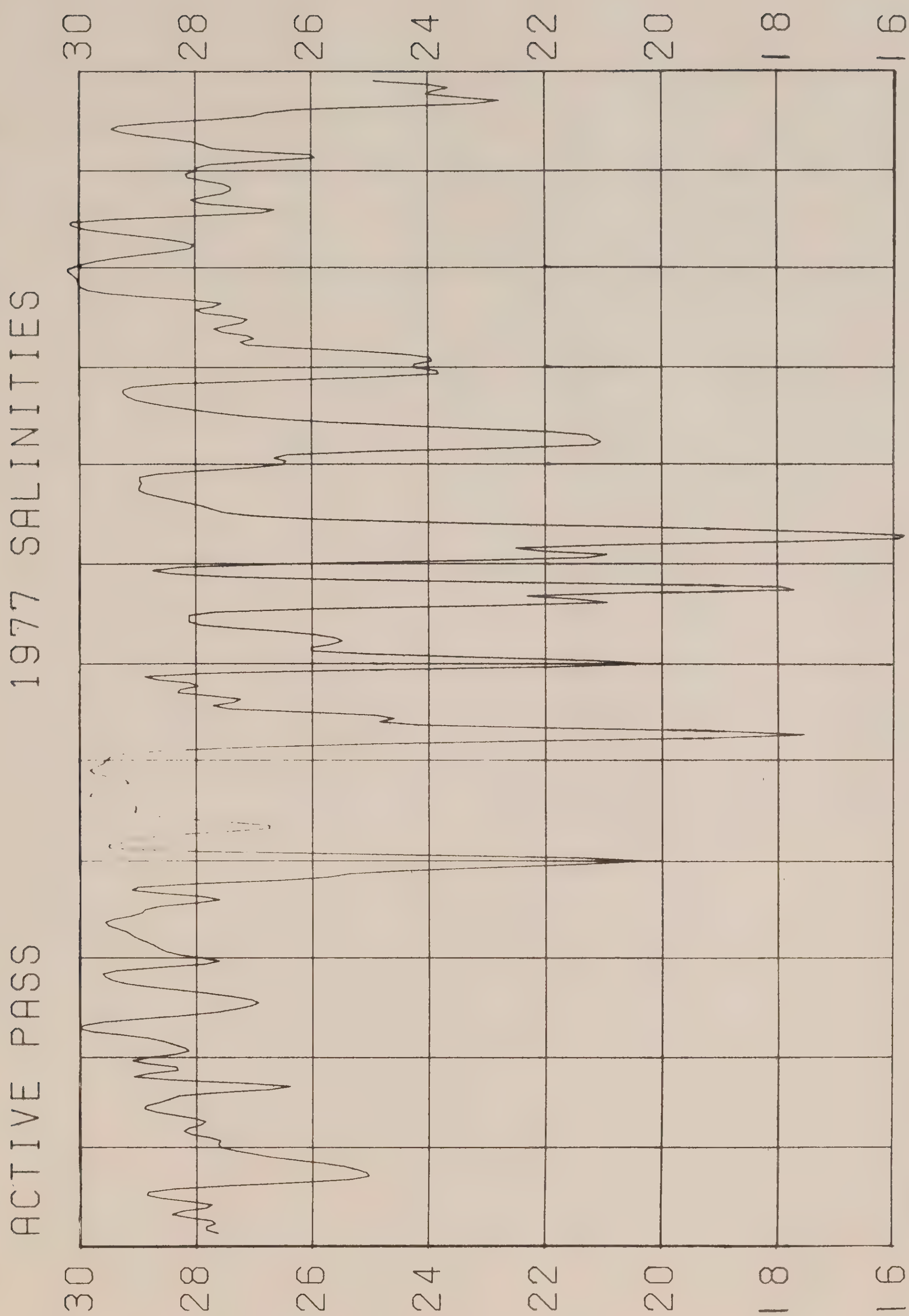
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Pacific Marine Science Report 80-2

NUTRIENT STORAGE BY FREEZING: DATA REPORT AND STATISTICAL ANALYSIS

by

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INSTITUTE OF OCEAN SCIENCES
Sidney, B.C.

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1980

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Acknowledgements

We thank D.M. Macdonald, D. Richardson and the officers and crew of the C.S.S. Parizeau for their assistance during sampling. J. Poulin and B. Mathias patiently produced the numerous tables and the manuscript.

Abstract

The effects of storage on the nutrients, reactive silicate, nitrate plus nitrite and soluble inorganic reactive orthophosphate are examined. Four large master samples were collected in a variety of coastal and estuarine waters. Subsampling was performed in such a manner to allow the investigation of the effects of filtering, quick freezing, normal freezing and length of storage time, as well as to enable a multi-replicate on-board determination of each nutrient. In addition, the optimum thaw times for each nutrient at all storage intervals were identified. The data and their statistical treatment (analysis of variance) are presented following descriptions of sampling procedure and analytical methodology.

Abbreviations

A	Factor A; Filtering - F, NF
ANOVA	Analysis of Variance
B	Factor B; Freezing - R, Q
C	Factor C; Time - 2w, 1m, 2m, 5m, 1y
D	Factor D; Sample 1, 2, 3, 4
DF	Degrees of freedom
F	Filtered
G	Samples determined on-board
H_A	Alternate hypothesis
H_O	Null hypothesis
n	Number of samples in a data set
NF	Not filtered
N	Nitrate
P	Phosphate
Q	Quick frozen (-20° Ethanol bath)
R	Regularly frozen (-10° Chest freezer)
S	Standard deviation
S °/oo	Salinity (parts per thousand)
Si	Silicate
T	Temperature °centigrade
t	Time between sample thaw and analysis
$\bar{X}$	Sample mean
1m	1 month
1y	1 year
2m	2 months
2w	2 weeks
5m	5 months
#	Master sample number
*	Significant (95%)
**	Highly significant (99%)
α	Level of significance
σ	Population standard deviation
Σ	Summation
χ^2	CHI-square statistic

Introduction

Among the tools of the oceanographer, the measurement of nutrients must be ranked near the top since it interfaces physical, chemical and biological processes. Routine on-board determination of nitrate, silicate and phosphate* is possible today using automated techniques and is of considerable advantage because it allows immediate feedback into the sampling programme and obviates the need for storage, which is a frequent cause of sample deterioration. However, it is not always possible to run on-board determinations for a variety of reasons; rough weather, instrument failure, insufficient space or scale of programme, to name a few. In such instances storage is required and many diverse methods are recommended. In conjunction with filtering, quick freezing, freezing or cooling to 4°C some examples of these methods are addition of $HgCl_2$, (Jenkins, 1968) or $CHCl_3$ (Gilmartin, 1964) for phosphate, H_2SO_4 for silicate (Grasshoff, 1976) and $HgCl_2$ or H_2SO_4 (Howe and Holley, 1969) for nitrate.

Adding preservatives during sampling significantly complicates the process, particularly if different preservatives are required for each nutrient. Also, the addition of a foreign material can contaminate not only the sample in question but other samples. Cross-contamination of samples destined for mercury analysis is possible if $HgCl_2$ is used as a preservative for several hundred nutrient samples even when stringent precautions are observed. For a number of years, we have preserved nutrient samples simply by freezing. As long as the tubes were not overfilled before being frozen in an upright position, valid nutrient analysis on the thawed samples appeared possible. Because the representativeness of these frozen samples had not been adequately considered, a programme was designed to investigate freezing as a technique of storage.

Experimental Design

Organization

We wished to examine the effect of storage, specifically by freezing, on the nutrients nitrate, silicate and phosphate. In addition to this basic theme we wanted to obtain information on other factors which might affect this storage technique such as filtering, length of time in the frozen state and the effect of quick freezing (-20°C, fluid bath) as opposed to regular freezing (-10°C in air). As this project entailed the handling of a large number of samples both physically and computationally, we realized before the study that an effective and simple coding system would be required. Because analysis of variance was to be applied to the data, the coding was established accordingly. Listed below are the factors which have been considered and the notation which has been used throughout the experiment and in this report when referring to the data.

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* Nitrate refers to the concentration of nitrate plus nitrite ions, silicate to the concentration of soluble reactive silicate ions and phosphate to the concentration of soluble reactive inorganic orthophosphate ions.

Factor A - Filtering (F, NF): 2 Levels

Each water sample obtained was immediately split and one half was filtered through a 0.45 μ membrane filter. The two levels of this factor have been designated as F (Filtered) and NF (Not Filtered).

Factor B - Freezing (Q, R): 2 Levels

The effect of freezing technique was investigated by using two processes: samples were either quick frozen in an ethanol bath at -20°C (Q) or frozen in in a normal chest freezer at about -10°C (R). In the tables the letter G has been used to designate subsamples which were analyzed immediately on-board (unfrozen) and these form the control data set.

Factor C - Storage Time (2w, 1m, 2m, 5m, 1y): 5 Levels

At five intervals: 2 weeks (2w); 1 month (1m); 2 months (2m); 5 months (5m); and 1 year (1y) appropriate numbers of samples were thawed and reactive nutrient determinations were performed in the shore based laboratory.

Factor D - Sample (1, 2, 3, 4): 4 Levels

Four separate water samples were obtained and the oceanographic data for each is summarized in Table 25. The number four was based strictly on the resources and time which we could afford to commit to this project, and the number of individual determinations required to adequately study each sample.

Subsamples have been coded according to the following scheme:

Factor D/Factor A/Factor B

For example the designation 1/NF/Q refers to a subsample drawn from sample 1, was not filtered and was quick frozen. Similarly, 3/F/R refers to a subsample of sample 3 which was subjected to filtering and then frozen in the chest freezer. From the large grouping of stored subsamples labelled in this fashion, samples were selected at random and analyzed at various time intervals. Data obtained in this manner are further classified according to the abbreviations given in factor C.

Shipboard Procedure

All four master samples were collected during a single cruise (OC-78-IS-002) on the CSS *Parizeau* in March 1978. The sampling region included the Fraser River estuary and Georgia Strait. Station locations are provided in Table 25. We attempted to gather water samples with a variety of characteristics (deep, shallow, high particulate, low particulate) in conjunction with a variety of salinities. A refractive salinometer was used to estimate salinity and ensure that the samples collected encompassed a range of salinities.

For each master sample a large volume of water was captured in a 30 L PVC Niskin sampler. Subsamples for dissolved oxygen, salinity and particle

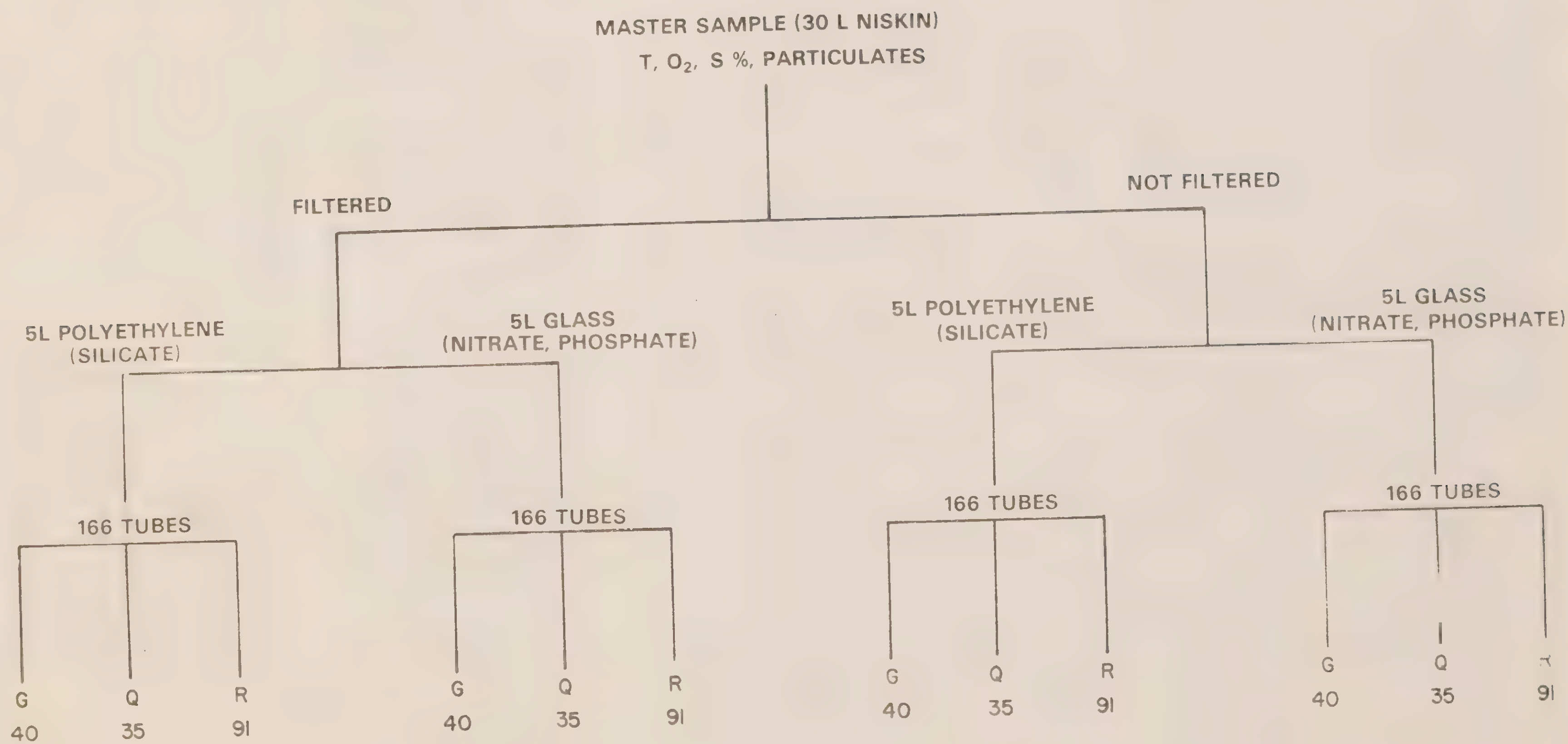
size distribution were first removed. The water was then split into four containers, two 4 L glass and two 4 L polyethylene carboys, one of each type for the unfiltered samples, the others designated for filtering. The glass carboys were used for samples destined for nitrate and phosphate determinations while the polyethylene was reserved for silicate determinations. Uniform mixing in the containers was assured by a magnetic stirrer and teflon-coated stirring bar. Samples were mixed continuously while water was siphoned into appropriate 15 mL test tubes (glass or polystyrene). Each tube and screw cap was rinsed twice before being filled to approximately the two-thirds mark. The organization scheme and numbers of tubes filled are given in Figure 1. From each carboy 166 tubes were filled, of these 40 were analyzed on-board, 35 were quick frozen at -20°C in an ethanol bath and 91 were frozen at -10°C in a chest freezer. All tubes were frozen in an upright position before being placed into zip-lock bags and labelled according to the aforementioned code. All of the zip-lock bags were collected together, placed in a large dark green polyethylene bag and stored in a chest freezer until needed. Colour coding was also employed to minimize the possibility of error during the rather hectic period when tubes were being rapidly filled and frozen.

While the unfiltered subsamples were being siphoned and frozen, the contents of the other two carboys were being vacuum filtered through a Millipore stainless steel apparatus. The filters (Millipore 0.45 μ membrane composed of mixed esters of cellulose acetate/nitrate) were washed with 300 to 500 mL of sample water prior to filtration into a 4 L glass receiving flask. On completion of filtering the sample was mixed continuously while subsamples were siphoned off and frozen as outlined above. Subsampling was not undertaken in any particular pattern, subsamples for Q or R treatments or for on-board determination were processed as they became available. The entire procedure took place in the ship's laboratory under fluorescent lights and special care was taken to exclude direct sunlight. The whole process of filtering, subsampling and freezing took from 1-2 hours to complete.

This procedure was repeated for each of the four master samples. Shipboard sample determinations were performed in the following order: 20 unfiltered, 20 filtered, 20 unfiltered and finally 20 filtered. By the time the last sample was determined by the AutoAnalyzer, the samples in the chest freezer were already frozen. Since Sample 4 was heavily laden with particulates (Fraser River water) filtering took an inordinately long time. For this sample, therefore, all on-board determinations were completed for the unfiltered samples before filtered ones became available. To give an idea of the times involved in the various steps the time tables for the four samples are given below.

Sample 1	28/3/78	(20 m, 29.34 $^{o}/oo$)
00:00	sample taken	
00:18	water in lab	
00:59	NF-glass into freezer	
01:20	NF-plastic into freezer	
01:25	NF-into AutoAnalyzer	
02:10	F-glass into freezer	
02:50	F-plastic into freezer	
02:50	F-into AutoAnalyzer	

FLOW SHEET FOR SUBSAMPLING



Q QUICK FROZEN
R FREEZER FROZEN
G ON-BOARD DETERMINATION (CONTROL DATA SET)

Figure 1

Sample 2	29/3/78	(1m, 28.81 ^{o}/oo)
00:00	sample taken	
00:15	water in lab	
00:25	NF-into AutoAnalyzer	
00:50	NF-plastic into freezer	
00:55	NF-glass into freezer	
01:50	F-into AutoAnalyzer	
02:50	F-plastic and glass into freezer	

Sample 3	29/3/78	(300 m, 30.77 ^{o}/oo)
00:00	sample taken	
00:15	water in lab	
00:25	NF-into AutoAnalyzer	
02:10	all samples in freezer	

Sample 4	30/3/79	(0 m, 1.05 ^{o}/oo)
00:00	sample taken	
00:17	water in lab	
00:54	NF-into AutoAnalyzer	
02:04	F-into AutoAnalyzer	
04:04	all sub samples frozen	

All glass and plasticware used during this experiment were cleaned by soaking in a 1N HCl for at least two hours. This was followed by three rinses with either glass distilled water in the case of the glassware or Milli-Q water for the plasticware prior to being inverted and allowed to air dry.

Shore Laboratory Procedure

The experiment was designed to collect sufficient water to conduct a storage test of a year's duration. At each time interval, (2 weeks, 1 month, 2 months, 5 months, 1 year), nine tubes from each group, filtered and not filtered, glass and plastic for each of the four master samples were taken randomly from the freezer, - a total of 720 tubes. The tubes were then grouped, one glass and one plastic, 1/F, 1/NF, 2/F ... 4/NF to be thawed and analyzed at specific thaw times. The thaw times chosen were 0, 0.5, 1, 2, 4, 6, 8, 18 and 24 hours.

Each group of frozen samples was placed in a rack and thawed at room temperature in front of an air fan. Immediately upon thawing the tubes were inverted and shaken to homogenize the liquid. This is an important step because during freezing, brine differentiates from the ice and during thawing the salt depleted ice floats thus creating salinity and nutrient gradients in the tube. In the process of being analyzed at appropriate thaw times the samples were placed on the laboratory bench top under fluorescent lights at ambient temperature. A few of the test tubes were placed in a cupboard from which light was excluded in order to determine the influence of ambient light on samples during thawing. All samples were shaken prior to transfer to the glass and plastic sample cups. There were eight samples to a group and as each sample/wash cycle took three minutes, each group required a total

of 24 minutes for analysis. All sample groups were ordered in the same manner on the sampling tray proceeding as 1/F, 1NF, 2F ... 4NF.

Calibration was performed with standards prepared in a 30.5 $^{o}/oo$ NaCl solution by Sagami Chemical Research Center, Japan. Standards were run at the beginning, middle and end of each day. The following day the data was reduced and compared to the on-board data in order to determine the optimum thaw time for each nutrient based on the closeness of agreement of stored samples with those determined on-board. On the following day five replicate determinations were performed for each of the groups 1/F/Q, 1/F/R, 1/NF/Q, ... 4/NF/R at the predetermined optimum thaw time.

Analytical Techniques

Nutrient determinations were performed using Technicon AutoAnalyzer II components; sampler IV, pump II, 3 colorimeters and heating bath with a plexiglass table designed to hold the various mixing coils and connectors required for the analytical procedure. Output from the colorimeters was read on two Technicon strip chart recorders. The sampler was modified to take two probes so that glass and plastic sampling cups could be simultaneously sampled, thereby reducing the time required for analysis. Based on information available in the literature (Grasshoff, 1976; Hassenteufel *et al.*, 1963; Mullin and Riley, 1955) phospate and nitrate were stored in glass and silicate was stored in plastic.

Soluble silicates were determined by the Technicon Industrial Method No. 186-72W. Both silicate and silicic acid in seawater react with an acid molybdate solution to form two isomers of 1,12 molybdosilicic acid. Control of both the pH and the acid/molybdate ratio allows the β-isomer to be selectively formed. The β-isomer is then reduced by ascorbic acid and this reduced complex exhibits a "molybdenum blue" color. Oxalic acid was introduced to prevent interference from orthophosphate ions. Measurement of the "molybdenum blue" complex was performed at 660 nm in a colorimeter with a silicon phototube. Quartz mixing coils were used to prevent contamination by borosilicate glass. Because there is a salt error when seawater samples are analyzed according to this method, standards were prepared in 30.5 $^{o}/oo$ NaCl.

Soluble orthophosphate was measured by using a modified Technicon method (Brynjolfson, 1973). Phosphate in seawater reacts with an acidic solution of ammonium molybdate and potassium antimonyl tartrate to form 1,12 molybdophosphoric acid. The acid/molybdate ratio is controlled to favour the β-isomer and to prevent hydrolysis of labile organophosphates. Antimony reduces the possibility of hydrolysis and catalyzes the formation of the coloured product. The β-molybdophosphoric acid is reduced by ascorbic acid to yield a phospho-molybdenum blue complex. The reagents are combined through a fitting before introduction to the seawater sample as the mixed reagent is not stable. The rate of complex formation is increased by passing the sample stream through a 37.5°C heating bath. This complex was measured at 880 nm in a colorimeter with a silicon phototube. Although there is not an appreciable salt effect with this method (<1%) the Sagami standards prepared in 30.5$^{o}/oo$ NaCl solution were used for standardization.

Technicon Industrial Method No. 158-71W was used for the determination of nitrate plus nitrite. Seawater was added to a solution of ammonium chloride at a pH of 8.5 and then passed through a copperized cadmium column to reduce the nitrate to nitrite. Ammonium chloride buffers the solution to prevent further reduction of the nitrite and also complexes any oxidized cadmium. The nitrite is then determined by a modified Griess-Ilosvay procedure. Nitrite was combined with a mixed color reagent comprising sulfanilamide, phosphoric acid and N-1-naphthylethylenediamine dihydrochloride. The nitrite reacts with the acidic sulfanilamide to form a diazo compound which couples with the diamine to form a reddish-purple azo dye. The intensity of the dye was measured at 550 nm in a colorimeter with a selenium phototube. Sagami nitrate standards prepared in a 30.5% NaCl solution were used for calibration as there is a slight salt effect with this method.

Oxygen was determined by the Micro-Winkler technique (Carpenter, 1965) in accordance with the procedure outlined in the Ocean Chemistry Division reference manual with an accuracy of ±0.02 mL L^{-1}.

Salinities were determined after the cruise with an Autolab inductive salinometer with duplicate determinations being within ±0.003 $^{o}/oo$. The accuracy of the salinity determination is ±0.02 $^{o}/oo$.

Particulate analysis was performed immediately on a TA II Coulter Counter with a 200 μ aperture.

Statistical Treatment of the Data

Data Ordering

For each of the four master samples the data have been catalogued according to nutrient species (nitrate, phosphate and silicate) and then according to filtering treatment (F, NF). Tables 1-24 are organized according to this plan and a guide at the front of the tables sets out the data groupings. The data are tabulated on right and left hand pages to facilitate comparison of filtered and not filtered results respectively. This form of presentation displays all of the data for a single nutrient and master sample on a two page spread. Additionally this format is logical in terms of the factors used in the analysis of variance subsequently applied to the results.

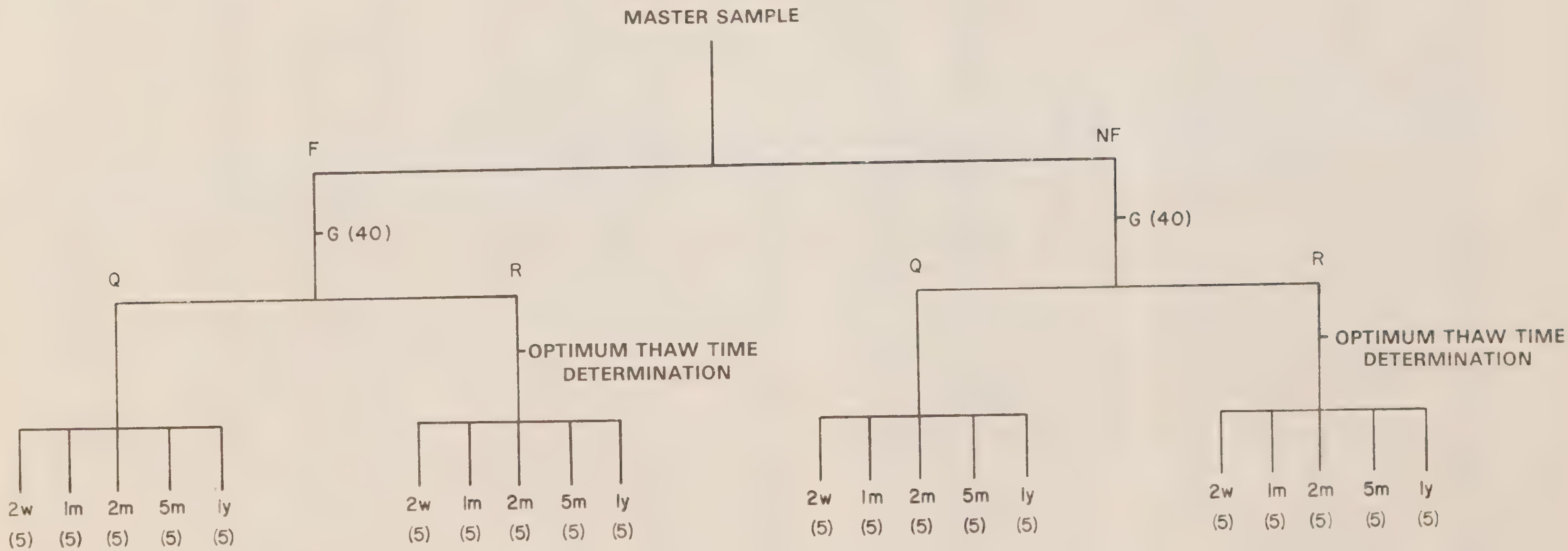
In each table the lower right hand section contains the basic cells (5 replicates) for two factors; storage time (2w, 1m, 2m, 5m, 1y) and freezing (Q,R). Comparison with the corresponding cross-page cell gives the third factor; filtering (F, NF). A four factor approach can be made by considering the 3 subsequent 2 page spreads for samples 2, 3 and 4.

Raw data from Tables 1-24 are summarized as averages ($\bar{X}$) and standard deviations (s) for nitrate,phosphate and silicate in Tables N-1, P-1, and Si-1 respectively.

Rejection Criteria

Since wild or "maverick" data points can dominate a statistical treatment these were deleted according to Chauvenet's criterion. A value was

FLOW SHEET FOR SAMPLE DETERMINATION AND
ANALYSIS OF VARIANCE



F FILTERED
NF NOT FILTERED
Q QUICK FROZEN
R FREEZER FROZEN
G ON-BOARD DETERMINATION (CONTROL DATA SET)

STORAGE TIME
2w 2 WEEKS
1m 1 MONTH
2m 2 MONTH
5m 5 MONTH
1y 1 YEAR

Figure 2

rejected only when the probability of observing it in a group of n replicates was not greater than 1/2 n. Critical values for this procedure were obtained from Overman & Clark (1960), and Table 26 displays the number of rejections with respect to storage time, freezing method and filtering for all three nutrients. Numerous on-board replications inspired confidence in the appropriateness of this technique. It is recognized that in routine sampling where there are neither large numbers of stored replicates nor good on-board determinations, this procedure is not possible. In order to maintain an equal number of replicates in all cells, rejected values were replaced by values taken from the preliminary thaw time investigation.

Procedure (Parametric versus Non-parametric)

In analysis of variance, two statistical techniques are available - parametric and non-parametric. The use of a parametric statistical treatment assumes that data exhibit homogeneity of variance (homoscedasticity) and a normal distribution and tests exist to verify these assumptions. Both techniques were considered for their applicability to the frozen data set and the on-board control data set in this study. The frozen data set was tested for homogeneity of variance using Bartlett's test (Bartlett, 1937) and the results are reported in Table 27. In all cases the null hypothesis (H_o: $\sigma_1 = \sigma_2 = \sigma_3 \ldots \sigma_n$) was rejected at the 99% confidence level. Because the variances in this data set were non-homogeneous non-parametric tests on hypotheses concerning the stored samples were employed. The normal distribution of the on-board control data set was tested by applying the goodness-of-fit test when sufficient replicates permitted. At the 95% confidence level the null hypothesis (H_o: the sample came from a normal population) could not be rejected. Thus, the on-board control data set followed a normal distribution. Because the variances were better behaved, standard t-tests were used in comparing data sets compiled from on-board determinations on the basis that the standard t-test is not seriously affected by moderate deviations in normal distribution and homogeneity of variance (Zar, 1974). The two-tailed paired-sample t-test was employed for comparison of samples thawed in the dark or under fluorescent laboratory light. This t-test is sufficiently robust to allow considerable departures from underlying assumptions especially when sample sizes are equal and two-tailed hypotheses are used (Boneau, 1960).

Statistical Tests

Each master sample was divided into two control sets (see Figure 2) - one for filtered and one for not filtered subsamples - and a series of replicated storage sets. Because the on-board determinations were not frozen, this data set was not included in the analysis of variance when applied to the method of freezing.

Storage data for each nutrient was subjected to a four-way non-parametric analysis of variance (Wilson, 1956) the factors (respective levels noted in parenthesis) were: Factor A, filtering (F, NF); Factor B, freezing (Q,R); Factor C, storage (2w, 1m, 2m, 5m, 1y); and Factor D, sample (1, 2, 3, 4).

The results of this preliminary analysis are reported in Tables N-2, P-2 and Si-2 for nitrate, phosphate and silicate respectively. In virtually all cases the variability in the data was overwhelmingly attributable to Factor D (sample), and any secondary effects related to Factor A (filtering) or Factor B (freezing) were indiscernable. In order to obtain additional information concerning the origin of variability in a given sample, a three-way non-parametric analysis of variance on each sample was performed. The factors and respective levels were: Factor A, filtering (F, NF); Factor B, freezing (Q, R); and Factor C, storage (2w, 1m, 2m, 5m, 1y). Results of the three-way non-parametric analysis of variance are summarized in Tables N-3, P-3 and Si-3. Significant interactions indicated by these results were investigated by plotting and are illustrated opposite the Tables.

Once it was established whether significant differences originated from freezing technique, filtering, or time of storage, comparisons between the 10 stored data groups (R, Q: 2w, 1m, 2m, 5m, 1y) and the appropriate control group could now be undertaken. In this respect, difficulty was encountered because the first group of duplicates was often significantly different from the second group determined approximately one hour later. (Table 28 lists the results of t-tests demonstrating that the second group of determinations was in some cases significantly higher and, in other cases significantly lower than the first group.) This variability might be explained by either genuine changes in the sample (growth of bacteria, lysing of cells or desorption from the walls, to cite a few possibilities) or by instrument drift. Because the direction of change followed no obvious pattern, it was concluded that the cause of variability originated with instrument drift. Accordingly, the first set of samples was used as the control group on the basis of researcher confidence in their representativeness of the original samples. The control group was compared to the stored sample data using a non-parametric one-way analysis of variance and the results from this test appear in Tables N-4, P-4 and Si-4 for the respective nutrients. If the results of the comparison indicate the null hypothesis (H_0: all means come from the same population) is rejected, as was the case for all three nutrients, examination of where differences occur may be made by applying a non-parametric ranking comparison of the storage data-sets to the control group (on-board determinations). This was performed using the method of Wilcoxon & Wilcox (1964) and results of this procedure are outlined for the respective nutrients in Tables N-5, P-5 and Si-5.

During the preliminary testing to determine the optimum thaw time when samples should be analyzed, some tubes were stored in the dark while others were left exposed to ambient laboratory lighting conditions (fluorescent lighting). For each nutrient a two-tailed paired-sample t-test was performed (Zar, 1974) and the results are given in Tables N-6, P-6 and Si-6.

A second question also addressed in Tables N-6, P-6, and Si-6 was whether or not quick freezing or regular freezing improved the precision (sample variance) during sample determination. This was also tested by the two-tailed paired-sample t-test.

Finally, a comparison between filtered and not filtered on-board determinations was performed using the standard students t-test since sample populations approach normality and variances are homogeneous. The results of the t-tests are summarized for all three nutrients in Table 29.

References

Bartlett, M.S. 1937. Some examples of statistical methods of research in agriculture and applied biology. J. Roy. Statist. Soc. Suppl. 4: 137-170.

Boneau, C.A. 1960. The effects of violations of assumptions underlying the t-test. Psychol. Bull. 57: 49-64.

Brynjolfson, S.J. 1973. A modification of the Technicon methodology for the determination of ortho-phosphate in seawater; its application to low level ortho-phosphate in fresh, saline and wastewater and total phosphate via a preliminary manual digestion. Presented at the Chemistry Laboratory Water Resources Service Seminar, Vancouver, B.C.

Carpenter, J.H. 1965. The Chesapeake Bay Institute technique for the Winkler dissolved oxygen method. Limnol. and Oceanogr. 10: 141-143.

Gilmartin, M. 1967. Changes in inorganic phosphate concentration occurring during seawater sample storage. Limnol and Oceanogr. 12: 325-328.

Grasshoff, K. 1976. Methods of Seawater Analysis. Weinheim, New York: Verlag Chemie. 317 pp.

Hassenteufel, W., Jagitsch, R., and Koczy, F.F. 1963. Impregnation of glass surface against sorption of phosphate traces. Limnol. and Oceanogr. 8: 152-156.

Howe, L.H. and Holley, C.W. 1969. Comparison of mercury (II) chloride and sulphuric acid as preservatives for nitrogen forms in water samples. Environ. Sci. and Tech. 3: 478-481.

Jenkins, D. 1967. The differentiation, analysis and preservation of nitrogen and phosphorus forms in natural waters. Trace inorganics in water. Adv. Chem. Ser. 73: 265-280.

Mullin, J.B. and Riley, J.P. 1955. The spectrophotometric determination of nitrate in natural waters, with particular reference to seawater. Anal. Chim. Acta 12: 464-479.

Overman, R.T. and Clark, H.M. 1960. Radioisotope techniques. New York: McGraw Hill. 476 pp.

Wilson, K.V. 1956. A distribution-free test of analysis of variance hypothesis. Psych. Bull. 53: 96-101.

Zar, J.H. 1974. Biostatistical analysis. Englewood Cliffs, N.J.: Prentice-Hall, Inc. 620 pp.

Tables

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Tables 1-8	Raw data for nitrate determinations
Tables 9-16	Raw data for phosphate determinations
Tables 17-24	Raw data for silicate determinations
Tables N-1, P-1, Si-1	Summary of all $\bar{X} \pm s$ for the respective nutrients
Tables N-3, P-2, Si-2	Wilson's non-parametric ANOVA (4-way) results for the respective nutrients
Tables N-3, P-3, Si-3	Wilson's non-parametric ANOVA (3-way) results for the respective nutrients
Tables N-4, P-4, Si-4	Wilson's non-parametric ANOVA (1-way) comparing on-board and stored data for the respective nutrients
Tables N-5, P-5, Si-5	Non-parametric comparison of the control with the stored data groups for the respective nutrients
Tables N-6, P-6, Si-6	a) Two-tailed paired-sample t-test comparing light and dark for the respective nutrients b) Two-tailed paired-sample t-test comparing S_Q and S_R for the respective nutrients
Table 25	Oceanographic data for the four master samples
Table 26	Rejection of data based on Chauvenet's criterion
Table 27	Bartlett's test for homogeneity of variances
Table 28	Comparison of the first set of on-board determinations with the second set
Table 29	Comparison of filtered and not filtered on-board determinations

GUIDE TO TABLES 1 - 24

On-board analysis date, Identification $\# / {}^{F}_{NF} / G$	thaw time (hours)	Length of time samples were stored; Date of sample thawing and analysis; Sample identification $\# / {}^{F}_{NF} / R$
	length of time between thawing and analysis	Nutrient concentration in μg at L^{-1} as a function of storage time and thaw time. * denotes thawing in the dark
		Analysis Date
		t = time between thawing and analysis
		Replicate (generally 5) sample analysis carried out at the optimum thaw time
		Sample Identification $\# / {}^{F}_{NF} / Q$
		Replicate (generally 5) analysis carried out on quick frozen samples at the optimum thaw time

\# Master sample number (1,2,3,4)
F Filtered
NF Not filtered
G Analyzed on board (no storage)
R Frozen at $10^{0}C$ in a chest freezer
Q Quick frozen at -20^{0} in an Ethanol bath

TABLE 1

NITRATE (UNFILTERED) #1
µg at L^{-1}

No Storage 28/3/78 1/NF/G		t thaw time (hours)	2 weeks 13/4/78 1/NF/R	1 month 25/4/78 1/NF/R	2 months 25/5/78 1/NF/R	5 months 5/9/78 1/NF/R	1 year 25/4/79 1/NF/R
26.7	26.6	0.0	26.6	26.8	26.8	26.1	22.3
27.0	26.3	0.5	26.6	26.8	26.9	26.5	26.3
27.0	26.4	1.0	26.6	26.4/27.9*	26.8	26.5	26.7
26.9	26.3	2.0	26.6	– /27.7*	27.0	26.5	26.5
26.9	26.5	4.0	26.7/26.9*	27.5/27.2*	26.9	26.9†	25.9
26.9	26.4	6.0	26.8/27.1*	–	27.0	27.1	26.6
26.9	26.5	7.0	–	–	26.9	–	–
26.9	26.4	8.0	–	–	–	27.0	25.8
25.3	26.5	9.0	26.5	–	–	–	–
26.9	26.5	17.0	27.8	–	–	–	–
27.0	26.4	18.0	–	26.9/26.8*	26.8	26.8/26.6*	26.4
26.8	26.4	24.0	26.8/26.8*	26.8/26.8*	26.8	27.1	–
26.8	26.5	29.0	–	–	–	–	–
26.8	26.4						
26.8	26.5		17/4/78	28/4/78	26/5/78	8/9/78	1/5/79
25.7	26.4		t = 1	t = 0	t = 0	t = 0	t = 2
26.8	26.5		26.6	26.3	26.5	26.3	26.2
26.8	26.4		26.6	26.4	26.6	26.2	26.2
27.1	26.5		26.7	26.3	26.6	26.6	26.7
26.3			26.6	26.3	26.6	26.6	26.3
			26.6	26.3	26.6	26.5	26.5
			1/NF/Q	1/NF/Q	1/NF/Q	1/NF/Q	1/NF/Q
			26.8	26.5	26.6	26.5	26.6
			26.6	26.3	26.0	26.3	26.7
			26.6	26.8	26.7	26.4	26.7
			26.5	26.3	26.6	26.4	26.6
			26.7	26.3	26.6	26.4	26.5

TABLE 2

NITRATE (FILTERED) #1

μg at L^{-1}

No. Storage 28/3/78 1/F/G		t thaw time (hours)	2 weeks 13/4/78 1/F/R	1 month 25/4/78 1/F/R	2 months 25/5/78 1/F/R	5 months 5/9/78 1/F/R	1 year 25/4/79 1/F/R
26.7	26.5	0.0	26.4	26.9	26.8	26.5	25.9
26.8	26.5	0.5	26.5	27.6	26.9	26.5	26.7
26.7	26.4	1.0	26.7	27.3/25.8*	26.8	26.5	26.7
26.8	26.5	2.0	24.8	– /26.8*	26.9	26.5	26.5
26.6	26.5	4.0	26.7/27.1*	27.2/25.2*	28.3	25.2†	26.6
26.7	26.5	6.0	26.8/26.3*	26.8	26.9	27.1	26.5
26.6	26.5	7.0	–	–	26.9	–	–
26.7	26.5	8.0	–	–	–	26.9	26.6
26.6	26.5	9.0	26.4	–	–	–	–
26.8	26.5	17.0	26.8	–	–	–	–
26.7	26.5	18.0	–	26.7/26.8*	27.0	26.2	26.6
26.7	26.5	24.0	26.8/26.7*	26.6/26.7*	26.8	27.0	–
26.7	26.5	29.0	–	–	–	–	–
26.7	26.4						
26.6	26.5		17/4/78	28/4/78	26/5/78	8/9/78	1/5/79
26.5	26.4		t = 0	t = 0	t = 2	t = 0	t = 1
26.5	26.5		26.3	26.4	26.7	26.5	26.3
26.6	26.5		26.5	26.4	26.7	25.8	26.6
26.5	26.6		26.3	26.5	26.8	26.3	26.7
26.6	25.5		26.4	26.4	26.6	26.4	25.8
26.6			26.4	26.4	26.6	–	26.7
			1/F/Q	1/F/Q	1/F/Q	1/F/Q	1/F/Q
			26.5	26.5	26.7	26.3	26.6
			26.6	26.3	26.6	26.3	26.6
			26.5	26.4	26.6	26.3	26.6
			26.5	26.4	26.6	26.3	26.6
			26.6	26.5	26.6	–	26.6

TABLE 3

NITRATE (UNFILTERED) #2
µg at L^{-1}

No Storage 29/3/78 2/NF/G		t thaw time (hours)	2 weeks 13/4/78 2/NF/R	1 month 25/4/78 2/NF/R	2 months 25/5/78 2/NF/R	5 months 5/9/78 2/NF/R	1 year 25/4/79 2/NF/R
24.5	24.8	0.0	20.8	24.3	24.7	24.8	26.8
24.5	24.9	0.5	24.5	24.9	24.8	22.8	24.6
24.7	24.7	1.0	24.4	25.6/26.7*	24.4	–	24.8
24.6	24.8	2.0	24.8	24.8/26.2*	25.1	24.6	24.0
24.6	24.8	4.0	24.8/24.8*	25.3/25.2*	24.4	20.9†	23.2
24.7	24.8	6.0	26.6/25.6*	–	25.0	24.4	24.7
24.6	24.8	7.0	–	–	24.9	–	–
24.6	24.8	8.0	–	–	–	24.6	24.5
24.7	24.9	9.0	24.7	–	–	–	–
24.6	24.8	17.0	24.7	–	–	–	–
24.7	24.9	18.0	–	25.0/25.0*	25.0	23.5	20.4
24.7	25.0	24.0	24.6/24.8*	24.5/25.0*	25.0	19.3	24.9
24.8	24.9	29.0	–	25.0	–	–	–
24.7	24.9						
24.7	24.9		17/4/78	28/4/78	26/5/78	8/9/78	1/5/79
24.7	24.9		t = 0.5	t = 2.0	t = 0.0	t = 0.0	t = 0.5
24.8	24.9		24.0	24.6	24.8	22.8	12.9
24.8	24.9		23.7	24.7	24.8	23.9	22.3
24.8	24.8		24.0	24.2	24.8	24.5	24.7
			24.0	24.6	24.7	21.9	23.1
			24.3	24.7	24.7	19.3	24.4
			2/NF/Q	2/NF/Q	2/NF/Q	2/NF/Q	2/NF/Q
			24.7	24.5	24.6	20.1	23.7
			24.7	24.8	24.3	23.4	25.1
			25.0	24.7	24.1	24.8	23.7
			24.8	24.8	24.7	24.1	24.3
			24.7	24.7	24.9	24.5	26.1

TABLE 4

NITRATE (FILTERED) #2

µg at L^{-1}

No Storage 29/3/78 2/F/G		t thaw time (hours)	2 weeks 13/4/78 2/F/R	1 month 25/4/78 2/F/R	2 months 25/5/78 2/F/R	5 months 5/9/78 2/F/R	1 year 25/4/79 2/F/R
24.7	24.8	0.0	24.8	25.1	25.3	24.8	26.9
24.7	24.9	0.5	24.8	25.1	25.0	24.8	24.9
24.8	24.8	1.0	24.8	25.5/27.8*	24.5	23.6	24.6
24.8	24.9	2.0	24.5	– /27.8*	21.9	24.4	25.0
24.9	24.9	4.0	19.5/24.7*	25.6/27.4*	25.1	24.8^{+}	24.6
24.6	24.9	6.0	26.6/25.4*	–	27.3	25.5	25.3
24.8	24.8	7.0	–	–	24.8	–	–
25.1	24.9	8.0	–	–	–	25.1	24.5
24.8	24.9	9.0	24.7	–	–	–	–
24.8	25.0	17.0	25.7	–	–	–	–
24.8	25.0	18.0	–	25.1/24.9*	24.4	24.6	24.6
24.7	25.0	24.0	24.9/24.8*	25.0/24.2*	22.7^{+}	23.1	24.4
24.8	25.1	29.0	–	–	–	–	–
24.9	24.2						
25.1	25.0		17/4/78	28/4/78	26/5/78	8/9/78	1/5/79
24.8	25.1		t = 0.5	t = 2.0	t = 0	t = 0.5	t = 1.0
25.0	25.1		24.7	24.6	24.8	23.1	25.1
24.9	25.1		24.6	24.7	17.9	24.6	22.1
24.8	25.1		24.7	24.7	24.9	24.7	24.0
24.8	25.0		24.7	24.2	24.9	24.8	24.5
24.8			24.7	24.8	24.8	24.6	23.4
			2/F/Q	2/F/Q	2/F/Q	2/F/Q	2/F/Q
			24.6	24.7	25.2	24.8	23.6
			24.8	24.7	24.7	24.6	24.9
			24.8	24.7	24.8	24.8	24.9
			23.3	24.7	24.9	24.4	25.0
			24.8	24.7	24.8	25.0	24.7

$^{+}$Plastic tube

TABLE 5

NITRATE (UNFILTERED) #3
μg at L^{-1}

No Storage 29/3/78 3/NF/G		t thaw time (hours)	2 weeks 13/4/78 3/NF/R	1 month 25/4/78 3/NF/R	2 months 25/5/78 3/NF/R	5 months 5/9/78 3/NF/R	1 year 25/4/79 3/NF/R
29.0	29.4	0.0	28.7	28.2	29.0	28.7	28.3
29.0	29.6	0.5	29.0	26.6	28.2	28.8	25.7
29.0	29.7	1.0	28.8	29.2/30.2*	28.9	27.5	28.8
28.9	29.6	2.0	28.6	29.1/29.0*	28.9	27.0	25.7
29.2	29.6	4.0	28.8/28.2*	28.1/28.9*	29.1	28.3†	28.5
29.1	29.6	6.0	28.9/28.8*	-	28.9	29.1	27.4
29.1	29.6	7.0	-	-	29.1	-	-
29.0	29.6	8.0	-	-	-	28.9	28.8
29.0	29.6	9.0	28.8	-	-	-	-
29.3	29.5	17.0	29.6	-	-	-	-
29.1	29.6	18.0	-	28.9/29.1*	28.8	28.1	28.9
29.1	29.4	24.0	28.4/27.9*	26.4/27.1*	29.2	29.1	28.9
29.2	29.5	29.0	-	28.3	-	-	-
29.2	29.5						
29.2	29.6		<u>17/4/78</u>	<u>28/4/78</u>	<u>26/5/78</u>	<u>8/9/78</u>	<u>1/5/79</u>
29.2	29.5		t = 0.5	t = 1.0	t = 0.0	t = 0.5	t = 1.0
29.2	29.5		28.8	28.4	27.7	27.7	28.7
29.1	29.5		28.9	27.9	28.8	28.6	26.4
29.1	29.5		28.7	28.6	28.5	25.5	28.7
29.1	29.5		28.5	28.5	28.7	28.7	28.4
			28.1	28.8	28.7	27.8	28.4
			3/NF/Q	3/NF/Q	3/NF/Q	3/NF/Q	3/NF/Q
			28.9	28.7	28.7	27.7	28.6
			28.8	28.5	28.8	28.6	28.7
			29.1	27.6	28.8	28.6	28.6
			29.0	29.0	28.8	28.5	29.5
			28.9	28.6	28.8	28.0	28.8

TABLE 6

NITRATE (FILTERED) #3
µg at L^{-1}

No Storage 29/3/78 3/F/G		t thaw time (hours)	2 weeks 13/4/78 3/F/R	1 month 25/4/78 3/F/R	2 months 25/5/78 3/F/R	5 months 5/9/78 3/F/R	1 year 25/4/79 3/F/R
29.3	29.5	0.0	23.5	22.7	28.9	28.6	29.0
29.4	29.5	0.5	29.0	29.1	18.5	28.8	26.0
29.4	29.0	1.0	24.0	29.5/29.9*	20.4	28.7	30.4
29.5	28.9	2.0	22.2	29.0/29.8*	25.4	30.2	29.0
29.5	29.0	4.0	19.3/29.3*	29.5/29.2*	18.2	30.3†	28.5
29.4	29.0	6.0	20.7/28.9*	–	19.9	29.3	30.7
29.4	29.0	7.0	–	–	28.8	–	–
29.6	28.8	8.0	–	–	–	28.4	28.3
29.5	28.9	9.0	28.8	–	–	–	–
29.5	28.9	17.0	28.9	–	–	–	–
29.4	28.9	18.0	–	29.0/28.9*	18.9	28.6	28.8
29.4	28.8	24.0	29.0/28.9*	28.9/28.8*	18.0	29.2	28.9
29.4	28.8	29.0	–	29.0	–	–	–
29.4	28.8						
29.4	29.8		17/4/78	28/4/78	26/5/78	8/9/78	1/5/79
29.6	29.9		t = 0.5	t = 0.5	t = 0.0	t = 0.5	t = 0.5
29.4	29.0		29.2	28.6	23.7	26.4	28.3
29.5	29.0		28.9	28.6	15.1	19.2	30.7
			28.9	28.6	28.7	28.6	27.9
			28.9	28.6	28.2	28.7	28.5
			28.9	28.9	28.7	28.6	29.0
			3/F/Q	3/F/Q	3/F/Q	3/F/Q	3/F/Q
			28.2	28.5	26.9	28.3	29.1
			28.9	28.6	28.1	28.4	29.8
			28.9	28.7	28.4	28.6	28.5
			28.1	28.7	28.0	28.6	29.8
			28.8	28.7	28.9	28.2	28.7

TABLE 7

NITRATE (UNFILTERED) #4
µg at L^{-1}

No Storage 30/3/78 4/NF/G		t thaw time (hours)	2 weeks 13/4/78 4/NF/R	1 month 25/4/78 4/NF/R	2 months 25/5/78 4/NF/R	5 months 5/9/78 4/NF/R	1 year 25/4/79 4/NF/R
11.4	11.3	0.0	11.7	11.4	10.4	11.4	11.5
11.4	11.3	0.5	11.7	11.5	11.5	11.4	11.4
11.5	11.4	1.0	11.7	11.5/11.6*	11.6	11.4	11.4
11.5	11.4	2.0	11.5	11.5/11.7*	11.1	10.8	11.1
11.5	11.3	4.0	11.6/12.6*	11.6/10.4*	11.5	11.2†	11.4
11.5	11.3	6.0	11.6/12.0*	11.3	11.6	11.6	9.5
11.5	11.4	7.0	-	-	10.5	-	-
11.5	11.4	8.0	-	-	-	11.5	11.3
11.5	11.2	9.0	11.6	-	-	-	-
11.5	11.5	17.0	11.7	-	-	-	-
11.4	11.5	18.0	-	11.6/11.5*	11.6	11.4	11.8
11.4	11.3	24.0	11.6/11.6*	11.5/11.5*	11.7	11.3	11.7
11.5	11.4	29.0	-	11.4	-	-	-
11.4	11.4						
11.5	11.5		17/4/78	28/4/78	26/5/78	8/9/78	1/5/79
11.4	11.4		t = 0.0	t = 0.5	t = 0.5	t = 1.0	t = 1.0
11.5	11.5		11.4	11.1	11.5	11.5	11.5
11.4	11.5		11.3	11.1	11.5	10.4	11.3
11.4	11.5		11.4	11.2	11.5	11.5	10.6
11.5	11.5		11.4	11.2	11.5	11.5	11.5
11.3	11.4		9.3	10.7	11.5	13.6	11.4
11.3	11.5						
11.3	11.5		4/NF/Q	4/NF/Q	4/NF/Q	4/NF/Q	4/NF/Q
11.3	11.5		11.4	11.1	13.1	10.7	11.5
11.3	11.4		11.4	11.4	12.0	14.8	11.6
11.3			11.4	11.3	11.1	13.7	12.2
			11.4	11.1	11.6	12.3	12.0
			11.4	11.2	11.6	12.8	12.4

TABLE 8

NITRATE (FILTERED) #4
μg at L^{-1}

No Storage 30/3/78 4/F/G		t thaw time (hours)	2 weeks 13/4/78 4/F/R	1 month 25/4/78 4/F/R	2 months 25/5/78 4/F/R	5 months 5/9/78 4/F/R	1 year 25/4/79 4/F/R
11.5	11.4	0.0	11.7	11.6	11.7	11.6	11.6
11.5	11.4	0.5	11.7	11.6	11.7	11.5	11.6
11.5	11.4	1.0	11.7	11.7/12.0*	11.8	11.5	11.6
11.5	11.5	2.0	11.7	11.7/12.4*	11.8	11.6	11.8
11.6	11.5	4.0	11.8/11.8*	11.7/11.6*	11.7	11.6†	11.6
11.5	11.5	6.0	11.7/11.7*	11.5	11.8	11.7	11.7
11.5	11.5	7.0	-	-	11.8	-	-
11.5	11.5	8.0	-	-	-	11.8	11.6
11.6	11.5	9.0	11.6	-	-	-	-
11.5	11.5	17.0	11.7	-	-	-	-
11.5	11.6	18.0	-	11.6/11.6*	11.7	11.5	10.7
11.6	11.6	24.0	11.7/11.8*	11.5/11.5*	11.8	11.7	11.6
11.6	11.6	29.0	-	11.7	-	-	-
11.5	11.5						
11.5	11.6		17/4/78	28/4/78	26/5/78	8/9/78	1/5/79
11.5	11.6		t = 0.0	t = 0.0	t = 0.0	t = 0.5	t = 0.0
11.5	11.6		11.7	11.2	11.5	11.6	11.6
11.6	11.5		11.6	11.3	11.6	11.6	11.6
11.6	11.5		11.6	11.2	11.6	11.6	12.2
11.5	11.6		11.6	11.3	11.6	11.6	11.7
11.3	11.6		11.6	11.3	11.6	11.6	11.7
11.4							
			4/F/Q	4/F/Q	4/F/Q	4/F/Q	4/F/Q
			11.6	11.3	11.6	11.6	13.2
			11.6	11.4	12.2	13.1	11.5
			11.6	11.3	11.5	11.6	11.7
			11.6	11.1	11.9	12.2	13.2
			11.6	11.4	11.5	12.4	11.7

TABLE 9

PHOSPHATE (UNFILTERED) #1
$\mu g\ at\ L^{-1}$

No Storage 28/3/78 1/NF/G		t thaw time (hours)	2 weeks 13/4/78 1/NF/R	1 month 25/4/78 1/NF/R	2 months 25/5/78 1/NF/R	5 months 5/9/78 1/NF/R	1 year 25/4/79 1/NF/R
2.40	2.40	0.0	2.38	2.36	2.36	2.36	1.99
2.40	2.40	0.5	2.37	-	2.44	2.34	2.37
2.41	2.40	1.0	2.36	2.36	2.51	2.16	2.11
2.39	2.40	2.0	2.40	2.37/2.31*	2.45	2.33	2.41
2.40	2.40	4.0	2.46/2.38*	2.43/2.41*	2.49	2.26†	2.41
2.40	2.41	6.0	2.39/2.38*	2.45	2.44	2.38	2.44
2.40	2.41	7.0	-	-	2.46	-	-
2.41	2.40	8.0	-	-	-	2.40	2.25
2.41	2.41	9.0	2.38	-	-	-	-
2.41	2.41	17.0	2.52	-	-	-	-
2.41	2.41	18.0	-	2.35/2.40*	2.52	2.37	2.10
2.42	2.42	24.0	2.36/2.34*	2.39/2.37*	2.44	2.35	-
2.40	2.42	29.0	-	2.41	-	-	-
2.40	2.41						
2.40	2.41		17/4/78	28/4/78	26/5/78	8/9/78	1/5/79
2.41			t = 1.0	t = 0.0	t = 0.0	t = 0.0	t = 2.0
			2.39	2.37	2.36	2.34	2.20
			2.42	2.31	2.35	2.27	2.31
			2.36	2.21	2.36	2.42	2.23
			2.39	2.29	2.39	2.43	2.20
			2.40	2.13	2.39	2.42	2.17
			1/NF/Q	1/NF/Q	1/NF/Q	1/NF/Q	1/NF/Q
			2.36	2.36	2.37	2.46	2.46
			2.36	2.36	2.35	2.44	2.46
			2.36	2.35	2.37	2.46	2.46
			2.36	2.35	2.37	2.46	2.47
			2.36	2.35	2.38	2.46	2.46

TABLE 10

PHOSPHATE (FILTERED) #1
μg at L-1

No Storage 28/3/78 1/F/G		t thaw time (hours)	2 weeks 13/4/78 1/F/R	1 month 25/4/78 1/F/R	2 months 25/5/78 1/F/R	5 months 5/9/78 1/F/R	1 year 25/4/79 1/F/R
2.40	2.41	0.0	2.28	2.34	2.18	2.40	2.25
2.40	2.40	0.5	2.27	2.30	2.23	2.37	2.40
2.40	2.42	1.0	2.34	2.35	2.24	2.31	2.11
2.40	2.41	2.0	2.16	2.33/2.24*	2.39	2.32	1.93
2.40	2.41	4.0	2.64/2.41*	2.38/2.23*	2.44	2.23†	2.13
2.40	2.41	6.0	2.35/2.33*	2.35	2.32	2.34	2.38
2.40	2.41	7.0	-	-	2.46	-	-
2.40	2.42	8.0	-	-	-	2.28	2.19
2.39	2.41	9.0	2.37	-	-	-	-
2.38	2.41	17.0	2.38	-	-	-	-
2.42	2.42	18.0	-	2.34/2.39*	2.39	2.35	1.95
2.40	2.41	24.0	2.37/2.30*	2.37/2.36*	2.36	2.39	-
2.40	2.41	29.0	-	2.36	-	-	-
2.40	2.41						
2.40	2.41		17/4/78	28/4/78	26/5/78	8/9/78	1/5/79
2.40	2.41		t = 0.0	t = 0.0	t = 2.0	t = 0.0	t = 1.0
2.38	2.40		2.32	2.34	2.35	2.34	2.43
2.42	2.42		2.34	2.29	2.39	2.42	2.47
2.41			2.35	2.31	2.36	2.49	2.38
			2.36	2.12	2.36	2.46	2.40
			2.30	2.64	2.31	2.38	2.17
			1/F/Q	1/F/Q	1/F/Q	1/F/Q	1/F/Q
			2.37	2.36	2.41	2.47	2.47
			2.37	2.36	2.42	2.49	2.48
			2.38	2.37	2.41	2.49	2.49
			2.37	2.37	2.40	2.49	2.47
			2.38	2.36	2.39	2.49	2.50

TABLE 11

PHOSPHATE (UNFILTERED) #2
µg at L-1

No Storage 29/3/78 2/NF/G		t thaw time (hours)	2 weeks 13/4/78 2/NF/R	1 month 25/4/78 2/NF/R	2 months 25/5/78 2/NF/R	5 months 5/9/78 2/NF/R	1 year 25/4/79 2/NF/R
2.27	2.26	0.0	1.89	2.15	2.28	2.22	2.21
2.27	2.26	0.5	2.22	2.14	2.31	2.09	2.27
2.26	2.17	1.0	2.19	2.21	2.24	-	2.30
2.26	2.25	2.0	2.27	2.25/2.33*	2.31	2.29	2.19
2.26	2.24	4.0	2.19/2.26*	2.27/2.21*	2.26	1.97†	2.17
2.26	2.25	6.0	2.21/2.33*	2.26	2.23	2.20	2.28
2.26	2.24	7.0	-	-	2.30	-	-
2.23	2.25	8.0	-	-	-	2.25	2.24
2.25	2.23	9.0	2.31	-	-	-	-
2.26	2.19	17.0	2.22	-	-	-	-
2.26	2.25	18.0	-	2.26/2.24*	2.24	2.14	2.00
2.25	2.25	24.0	2.26/2.22*	2.21/2.25*	2.31	1.88	2.10
2.26	2.25	29.0	-	2.20	-	-	-
2.28	2.25						
2.24	2.25		17/4/78	28/4/78	26/5/78	8/9/78	1/5/79
2.25	2.25		t = 0.5	t = 2.0	t = 0.0	t = 0.0	t = 0.5
2.26	2.12		2.17	2.22	2.19	2.19	2.05
2.25	2.25		2.14	2.18	2.20	2.30	2.09
2.25	2.20		2.20	2.18	2.17	2.34	2.25
2.25			2.19	2.10	2.19	2.17	2.19
			2.21	2.21	2.22	1.96	1.82
			2/NF/Q	2/NF/Q	2/NF/Q	2/NF/Q	2/NF/Q
			2.24	2.18	2.21	2.00	2.15
			2.25	2.23	2.16	2.04	2.28
			2.25	2.21	2.12	2.27	2.23
			2.24	2.21	2.25	1.81	2.12
			2.24	2.18	2.24	2.27	2.29

TABLE 12

PHOSPHATE (FILTERED) #2
μg at L^{-1}

No Storage 29/3/78 2/F/ G		t thaw time (hours)	2 weeks 13/4/78 2/F/R	1 month 25/4/78 2/F/R	2 months 25/5/78 2/F/R	5 months 5/9/78 2/F/R	1 year 25/4/79 2/F/R
2.21	2.23	0.0	2.23	2.06	2.24	2.26	1.91
2.22	2.23	0.5	2.22	2.18	2.06	2.23	1.91
2.23	2.21	1.0	2.19	2.20	2.28	2.13	2.21
2.23	2.24	2.0	2.19	2.23/2.35*	2.07	2.07	1.94
2.22	2.26	4.0	– /2.17*	2.27/2.44*	2.35	2.01†	1.97
2.22	2.22	6.0	2.18/2.30*	2.26	2.29	2.24	1.78
2.23	2.14	7.0	–	–	2.27	–	–
2.20	2.25	8.0	–	–	–	2.25	1.68
2.22	2.23	9.0	2.28	–	–	–	–
2.22	2.22	17.0	2.32	–	–	–	–
2.23	2.23	18.0	–	2.23/2.20*	2.24	2.21	2.05
2.23	2.15	24.0	2.26/2.18*	2.23/2.20*	2.07	2.12	1.81
2.23	2.24	29.0	–	2.23	–	–	–
2.26	2.25						
2.29	2.23		<u>17/4/78</u>	<u>28/4/78</u>	<u>26/5/78</u>	<u>8/9/78</u>	<u>1/5/79</u>
2.22	2.24		t = 0.5	t = 2.0	t = 0.0	t = 0.5	t = 1.0
2.19	2.22		2.24	2.16	2.20	2.19	2.14
2.21	2.25		2.20	2.17	1.70	2.25	2.05
2.21	2.24		2.22	2.16	2.20	2.23	2.06
2.22	2.24		2.24	2.13	2.26	2.27	2.56
2.24			2.22	2.17	2.20	2.30	1.93
			2/F/Q	2/F/Q	2/F/Q	2/F/Q	2/F/Q
			2.22	2.19	2.25	2.34	2.05
			2.22	2.19	2.26	2.34	2.32
			2.22	2.19	2.26	2.06	2.22
			2.22	2.19	2.24	2.27	2.29
			2.21	2.19	2.25	2.34	2.24

TABLE 13

PHOSPHATE (UNFILTERED) #3
μg at L-1

No Storage 29/3/78 3/NF/G		t thaw time (hours)	2 weeks 13/4/78 3/NF/R	1 month 25/4/78 3/NF/R	2 months 25/5/78 3/NF/R	5 months 5/9/78 3/NF/R	1 year 25/4/79 3/NF/R
2.83	2.83	0.0	2.78	2.69	2.76	2.69	2.62
2.76	2.83	0.5	2.78	2.57	2.65	2.66	2.58
2.80	2.81	1.0	2.52	2.77	2.79	2.64	2.72
2.80	2.83	2.0	2.78	2.63/2.76*	2.82	2.62	2.57
2.81	2.83	4.0	2.72/2.72*	2.67/2.73*	2.75	2.70†	2.88
2.82	2.83	6.0	2.78/2.78*	2.71	2.77	2.72	2.58
2.81	2.83	7.0	-	-	2.82	-	-
2.65	2.83	8.0	-	-	-	2.73	2.76
2.74	2.83	9.0	2.86	-	-	-	-
2.83	2.82	17.0	2.79	-	-	-	-
2.81	2.82	18.0	-	2.76/2.78*	2.88	2.43	2.86
2.83	2.82	24.0	2.77/2.66*	2.58/2.63*	2.82	2.72	2.85
2.84	2.82	29.0	-	2.69	-	-	-
2.72	2.83						
2.81	2.82		17/4/78	28/4/78	26/5/78	8/9/78	1/5/79
2.84	2.82		t = 0.5	t = 1.0	t = 0.0	t = 0.5	t = 1.0
2.84	2.84		2.81	2.64	2.63	2.80	2.86
2.70	2.84		2.81	2.66	2.58	2.87	2.67
2.61	2.82		2.79	2.74	2.62	2.64	2.86
2.80	2.82		2.77	2.72	2.63	2.95	2.84
			2.76	2.69	2.60	2.61	2.73
			3/NF/Q	3/NF/Q	3/NF/Q	3/NF/Q	3/NF/Q
			2.78	2.77	2.77	2.53	2.88
			2.78	2.75	2.63	2.91	2.66
			2.79	2.40	2.78	2.91	2.86
			2.80	2.54	2.80	2.91	2.73
			2.79	2.77	2.78	2.83	2.88

TABLE 14

PHOSPHATE (FILTERED) #3
μg at L^{-1}

No Storage 29/3/78 3/F/G		t thaw time (hours)	2 weeks 13/4/78 3/F/R	1 month 25/4/78 3/F/R	2 months 25/5/78 3/F/R	5 months 5/9/78 3/F/R	1 year 25/4/79 3/F/R
2.80	2.80	0.0	2.40	2.20	2.82	2.65	2.38
2.80	2.83	0.5	2.76	2.77	1.98	2.66	2.58
2.79	2.80	1.0	2.32	2.77	2.00	2.71	2.92
2.79	2.80	2.0	2.32	2.73/2.79*	2.48	2.91	2.18
2.80	2.80	4.0	1.97/2.83*	2.77/2.77*	2.04	2.81†	2.74
2.81	2.80	6.0	2.13/2.78*	2.78	2.11	2.79	2.88
2.79	2.80	7.0	-	-	2.80	-	-
2.82	2.81	8.0	-	-	-	2.72	2.71
2.80	2.81	9.0	2.85	-	-	-	-
2.80	2.82	17.0	2.71	-	-	-	-
2.80	2.83	18.0	-	2.75/2.76*	2.16	2.25	2.65
2.80	2.81	24.0	2.78/2.74*	2.78/2.75*	2.03	2.63	2.44
2.80	2.81	29.0	-	2.78	-	-	-
2.81	2.81						
2.80	2.81		17/4/78	28/4/78	26/5/78	8/9/78	1/5/79
2.80	2.80		t = 0.5	t = 0.5	t = 0.0	t = 0.5	t = 1.0
2.81	2.80		2.71	2.73	2.28	2.25	2.76
2.81			2.76	2.73	1.81	1.96	2.97
			2.71	2.73	2.65	2.85	2.17
			2.78	2.73	2.71	2.57	2.50
			-	2.83	2.66	2.74	1.58
			3/F/Q	3/F/Q	3/F/Q	3/F/Q	3/F/Q
			2.64	2.74	2.68	2.80	2.84
			2.58	2.75	2.75	2.83	2.49
			2.73	2.76	2.74	2.87	2.32
			2.63	2.66	2.70	2.87	2.48
			2.70	2.74	2.80	2.53	2.08

TABLE 15

PHOSPHATE (UNFILTERED) #4
μg at L^{-1}

No Storage 30/3/78 4/NF/G		t thaw time (hours)	2 weeks 13/4/78 4/NF/R	1 month 25/4/78 4/NF/R	2 months 25/5/78 4/NF/R	5 months 5/9/78 4/NF/R	1 year 25/4/79 4/NF/R
1.03	1.02	0.0	1.17	0.65	0.81	0.79	1.01
1.04	0.97	0.5	0.70	0.73	0.82	0.79	0.87
1.00	0.96	1.0	0.70	0.61	0.82	0.80	0.97
1.01	0.97	2.0	0.65	– /0.61*	0.79	0.73	0.85
1.03	0.97	4.0	0.51/0.82*	0.54/0.65*	–	0.80†	0.96
0.98	1.00	6.0	0.66/0.42*	0.47	0.74	0.73	0.83
0.91	0.93	7.0	–	–	0.70	–	–
0.95	1.03	8.0	–	–	–	0.78	0.88
0.93	0.92	9.0	0.66	–	–	–	–
0.92	0.94	17.0	0.68	–	–	–	–
0.91	0.94	18.0	–	0.58/0.59*	0.85	0.79	0.90
0.91	0.97	24.0	0.58/0.61*	0.59/0.60*	0.85	0.63	0.89
0.91	0.97	29.0	–	0.59	–	–	–
0.91	0.96						
0.92	0.96		17/4/78	28/4/78	26/5/78	8/9/78	1/5/79
0.92	0.97		t = 0.0	t = 0.5	t = 0.5	t = 1.0	t = 1.0
0.90	0.97		0.75	1.02	0.72	0.74	0.82
0.90	0.86		0.69	0.95	0.77	0.87	0.82
0.97	0.88		0.60	0.95	0.77	0.83	0.79
1.03	0.97		0.65	0.88	0.87	0.83	0.77
			–	0.88	0.68	0.72	0.78
			4/NF/Q	4/NF/Q	4/NF/Q	4/NF/Q	4/NF/Q
			1.09	1.09	1.03	1.02	1.13
			1.12	1.15	1.04	1.06	1.09
			1.07	1.03	1.06	1.06	1.13
			1.06	1.04	1.07	1.06	1.09
			1.09	1.05	1.06	1.06	1.11

TABLE 16

PHOSPHATE (FILTERED) #4
µg at L-1

No Storage 30/3/78 4/F/G		t thaw time (hours)	2 weeks 13/4/78 4/F/R	1 month 25/4/78 4/F/R	2 months 25/5/78 4/F/R	5 months 5/9/78 4/F/R	1 year 25/4/79 4/F/R
0.29	0.30	0.0	0.31	0.30	0.31	0.36	0.30
0.30	0.30	0.5	0.30	0.30	0.32	0.29	0.29
0.30	0.29	1.0	0.26	0.30	0.39	0.33	0.31
0.30	0.31	2.0	0.38	- /0.29*	0.34	0.29	0.29
0.30	0.30	4.0	0.28/0.33*	0.31/0.28*	0.36	0.29†	0.28
0.31	0.30	6.0	0.32/0.30*	0.30	0.33	0.22	0.33
0.30	0.29	7.0	-	-	0.35	-	-
0.30	0.30	8.0	-	-	-	0.26	0.33
0.30	0.30	9.0	0.42	-	-	-	-
0.30	0.30	17.0	0.23	-	-	-	-
0.29	0.31	18.0	-	0.28/0.30*	0.39	0.29	0.34
0.30	0.30	24.0	0.32/0.28*	0.28/0.30*	0.32	0.29	0.34
0.30	0.30	29.0	-	0.30	-	-	-
0.30	0.30						
0.29	0.30		<u>17/4/78</u>	<u>28/4/78</u>	<u>26/5/78</u>	<u>8/9/78</u>	<u>1/5/79</u>
0.29	0.30		t = 0.0	t = 0.0	t = 0.0	t = 0.5	t = 0.0
0.31	0.30		0.31	0.30	0.28	0.30	0.36
0.33	0.28		0.33	0.30	0.29	0.36	0.30
0.31	0.29		0.34	0.29	0.28	0.30	0.31
			0.33	0.30	0.29	0.30	0.31
			0.32	0.28	0.28	0.30	-
			4/F/Q	4/F/Q	4/F/Q	4/F/Q	4/F/Q
			0.33	0.29	0.29	0.30	0.32
			0.32	0.30	0.34	0.32	0.32
			0.32	0.29	0.29	0.30	0.31
			0.32	0.29	0.29	0.30	0.29
			0.31	0.29	0.29	0.30	0.30

TABLE 17

SILICATE (UNFILTERED) #1
μg at L^{-1}

No Storage 28/3/78 1/NF/G		t thaw time (hours)	2 weeks 13/4/78 1/NF/R	1 month 25/4/78 1/NF/R	2 months 25/5/78 1/NF/R	5 months 5/9/78 1/NF/R	1 year 25/4/79 1/NF/R
54.2	54.3	0.0	53.5	53.3	54.0	51.3	46.4
54.1	54.3	0.5	53.9	52.9	53.2	51.4	44.8
54.2	54.2	1.0	54.3	54.9/54.4*	54.2	51.4	48.2
54.1	54.0	2.0	53.8	53.6/56.3*	52.7	51.3	49.0
54.2	54.0	4.0	54.6/51.8*	53.3/54.5*	55.1	52.3†	50.4
54.2	53.8	6.0	52.4/68.4*	54.2	54.1	52.7	51.3
54.1	53.8	7.0	-	-	54.1	-	-
54.1	53.8	8.0	-	-	-	52.8	52.6
54.0	53.9	9.0	54.4	-	-	-	-
54.0	54.0	17.0	57.1	-	-	-	-
53.9	54.0	18.0	-	54.1/54.1*	54.2	58.0	54.0
53.9	54.1	24.0	56.2/53.5*	54.1/54.1*	54.2	52.4	-
54.1	54.1	29.0	-	56.8	-	-	-
54.1	54.1						
54.0	54.0		17/4/78	28/4/78	26/5/78	8/9/78	1/5/79
54.2	53.9		t = 1.0	t = 1.0	t = 0.0	t = 3.0	t = 18.0
54.2	53.8		52.6	53.7	52.8	51.8	53.4
54.2	53.8		52.6	52.0	53.4	51.8	54.6
54.1	53.7		52.9	53.8	52.8	52.0	52.9
51.1	53.7		52.6	53.8	52.7	52.2	52.3
			52.9	53.8	52.8	52.2	53.0
			1/NF/Q	1/NF/Q	1/NF/Q	1/NF/Q	1/NF/Q
			52.6	54.2	52.9	52.7	53.8
			52.5	53.7	53.1	52.6	54.4
			52.5	53.7	53.4	52.6	54.3
			52.9	53.8	53.2	52.8	54.5
			52.5	54.1	53.1	53.0	54.5

TABLE 18

SILICATE (FILTERED) #1
μg at L-1

No Storage 28/3/78 1/F/G		t thaw time (hours)	2 weeks 13/4/78 1/F/R	1 month 25/4/78 1/F/R	2 months 25/5/78 1/F/R	5 months 5/9/78 1/F/R	1 year 25/4/79 1/F/R
54.2	53.6	0.0	53.7	52.6	53.5	51.3	52.7
54.1	53.6	0.5	53.9	54.0	53.4	52.2	51.6
54.1	53.7	1.0	54.6	54.9/46.8*	54.7	52.6	51.9
54.0	53.6	2.0	54.0	53.9/61.7*	52.0	51.9	52.5
54.0	53.6	4.0	53.9/82.7*	54.0/55.6*	54.3	54.3†	53.2
54.1	53.6	6.0	55.0/57.3*	59.2	54.1	56.6	50.7
54.0	53.6	7.0	-	-	54.3	-	-
54.1	53.6	8.0	-	-	-	53.2	54.1
53.6	53.7	9.0	55.3	-	-	-	-
53.8	53.6	17.0	60.6	-	-	-	-
54.0	53.5	18.0	-	54.4/60.5*	55.8	54.8	54.4
53.7	53.6	24.0	59.5/54.6*	54.1/63.9	54.2	53.8	-
54.0	53.5	29.0	-	-	-	-	-
54.0	53.2						
54.0	53.2		17/4/78	28/4/78	26/5/78	8/9/78	1/5/79
54.2	53.3		t = 1.0	t = 0.5	t = 0.0	t = 3.0	t = 4.0
54.2	53.5		52.8	54.5	53.1	52.4	49.6
54.1	53.2		58.8	53.9	52.8	54.7	55.1
53.9	53.3		62.6	53.6	52.6	52.2	54.5
54.0	53.3		55.2	53.8	53.4	52.8	54.8
			58.7	53.6	-	52.6	48.8
			1/F/Q	1/F/Q	1/F/Q	1/F/Q	1/F/Q
			68.5	53.8	53.0	53.0	54.2
			53.1	53.6	53.3	52.9	53.3
			55.9	53.8	52.8	53.2	54.6
			54.5	53.6	53.0	52.4	55.1
			52.4	53.8	52.9	52.4	54.6

TABLE 19

SILICATE (UNFILTERED) #2
µg at L^{-1}

No Storage 29/3/78 2/NF/G		t thaw time (hours)	2 weeks 13/4/78 2/NF/R	1 month 25/4/78 2/NF/R	2 months 25/5/78 2/NF/R	5 months 5/9/78 2/NF/R	1 year 25/4/79 2/NF/R
54.2	54.2	0.0	53.9	53.9	53.8	52.4	52.8
54.2	54.2	0.5	54.3	54.0	56.1	52.6	51.7
54.1	54.2	1.0	54.7	55.2/60.5*	53.9	–	51.1
54.1	54.1	2.0	54.2	54.5/58.5*	53.6	53.1	53.2
54.2	54.4	4.0	54.4/55.6*	54.4/54.3*	54.4	52.9†	52.9
54.2	54.2	6.0	52.8/57.7*	54.3	54.3	54.0	53.3
54.1	54.1	7.0	–	–	54.8	–	–
54.4	54.0	8.0	–	–	–	54.0	53.8
54.2	54.2	9.0	54.2	–	–	–	–
54.2	54.4	17.0	65.9	–	–	–	–
54.1	54.3	18.0	–	53.4/54.8*	53.6	53.4	54.6
54.2	54.3	24.0	58.8/54.2*	54.8/54.5*	55.0	54.0	54.9
54.2	54.2	29.0	–	54.7	–	–	–
54.3	54.3						
54.2	54.3		17/4/78	28/4/78	26/5/78	8/9/78	1/5/79
54.1	54.3		t = 1.0	t = 0.5	t = 1.0	t = 6.0	t = 18.0
54.4	54.3		55.0	54.6	53.4	61.2	55.6
54.2	54.2		55.0	54.6	53.6	55.7	54.2
54.3	54.3		54.6	54.5	53.6	55.5	53.8
54.3	54.4		54.3	53.2	53.6	55.5	54.8
54.2			54.1	54.5	53.4	55.9	54.5
			2/NF/Q	2/NF/Q	2/NF/Q	2/NF/Q	2/NF/Q
			53.9	54.3	53.4	56.1	54.9
			54.9	53.4	53.8	55.5	52.4
			53.9	53.6	53.4	56.3	50.4
			54.2	54.5	53.5	55.9	55.0
			54.5	53.1	53.7	52.2	53.0

TABLE 20

SILICATE (FILTERED) #2
µg at L^{-1}

No Storage 29/3/78 2/F/G		t thaw time (hours)	2 weeks 13/4/78 2/F/R	1 month 25/4/78 2/F/R	2 months 25/5/78 2/F/R	5 months 5/9/78 2/F/R	1 year 25/4/79 2/F/R
54.2	54.4	0.0	49.4	54.0	51.9	46.0	51.4
54.1	54.2	0.5	51.0	54.0	54.1	53.2	51.7
54.3	54.3	1.0	54.7	55.2/55.7*	53.9	44.7	48.7
54.2	54.4	2.0	54.5	54.5/51.8*	53.6	53.9	50.7
54.3	54.4	4.0	54.2/55.3*	53.6/54.1*	55.0	53.1†	52.6
54.1	54.3	6.0	52.2/59.3*	49.2	53.8	54.2	49.6
54.2	54.4	7.0	–	–	56.4	–	–
54.3	54.3	8.0	–	–	–	52.0	41.0
54.2	54.4	9.0	56.2	–	–	–	–
54.1	54.4	17.0	56.1	–	–	–	–
54.1	54.3	18.0	–	51.6/54.8*	55.2	55.8	45.4
54.2	54.4	24.0	53.6/53.3*	55.2/48.7*	47.9	56.1	–
54.3	54.5	29.0	–	54.5	–	–	–
54.3	54.3						
54.2	54.3		<u>17/4/78</u>	<u>28/4/78</u>	<u>26/5/78</u>	<u>8/9/78</u>	<u>1/5/79</u>
54.1	54.5		t = 1.0	t = 0.0	t = 1.0	t = 2.0	t = 4.0
54.1	54.4		53.8	55.0	51.8	30.3	52.8
54.2	54.4		53.8	54.3	43.7	52.7	54.6
54.1	54.5		53.4	54.3	52.3	52.6	54.2
54.3	54.3		54.1	54.5	55.6	53.2	52.0
54.6			53.8	54.3	49.9	54.1	49.8
			2/F/Q	2/F/Q	2/F/Q	2/F/Q	2/F/Q
			53.8	54.1	62.6	51.4	53.1
			53.7	55.0	53.3	52.7	52.9
			53.7	54.3	53.4	52.2	53.4
			53.4	54.3	53.6	52.4	52.9
			53.7	54.9	55.3	52.1	53.3

TABLE 21

SILICATE (UNFILTERED) #3
µg at L^{-1}

No Storage 29/3/78 3/NF/G		t thaw time (hours)	2 weeks 13/4/78 3/NF/R	1 month 25/4/78 3/NF/R	2 months 25/5/78 3/NF/R	5 months 5/9/78 3/NF/R	1 year 25/4/79 3/NF/R
65.6	65.3	0.0	65.7	65.5	65.6	64.4	62.4
65.7	65.5	0.5	65.7	65.9	65.5	64.0	62.5
65.8	65.5	1.0	64.3	66.8/67.2*	65.8	64.4	63.0
65.7	65.4	2.0	64.9	65.8/66.1*	65.5	65.0	63.1
65.7	65.6	4.0	65.9/71.5*	66.2/65.7*	66.8	64.6†	63.7
65.7	65.4	6.0	66.7/70.7*	65.2	65.9	67.3	64.8
65.8	65.3	7.0	-	-	66.0	-	-
65.6	65.4	8.0	-	-	-	65.5	64.6
65.8	65.4	9.0	65.5	-	-	-	-
65.7	65.4	17.0	65.5	-	-	-	-
65.9	65.3	18.0	-	66.3/66.3*	66.4	65.2	65.7
65.8	65.5	24.0	66.1/67.6*	66.3/66.4*	63.6	65.7	66.0
65.7	65.3	29.0	-	65.5	-	-	-
65.6	65.4						
65.9	65.4		17/4/78	28/4/78	26/5/78	8/9/78	1/5/79
65.8	65.5		t = 0.0	t = 0.0	t = 0.0	t = 2.0	t = 18.0
65.7	65.5		65.4	68.7	65.1	64.7	65.7
65.7	65.3		65.6	66.0	64.7	64.6	66.6
65.7	65.3		65.4	66.3	65.2	64.6	66.5
65.7	65.3		65.4	65.7	64.9	64.6	65.7
			65.6	65.9	65.5	64.9	66.2
			3/NF/Q	3/NF/Q	3/NF/Q	3/NF/Q	3/NF/Q
			65.3	65.7	63.9	62.6	67.3
			64.3	66.0	65.0	62.9	66.6
			65.6	66.0	64.9	64.7	65.5
			65.6	65.7	59.6	64.3	68.2
			65.6	66.4	66.2	66.0	64.4

TABLE 22

SILICATE (FILTERED) #3
µg at L^{-1}

No Storage 29/3/78 3/F/G		t thaw time (hours)	2 weeks 13/4/78 3/F/R	1 month 25/4/78 3/F/R	2 months 25/5/78 3/F/R	5 months 5/9/78 3/F/R	1 year 25/4/79 3/F/R
65.6	65.6	0.0	65.3	65.4	65.3	63.2	50.9
65.6	65.6	0.5	65.7	65.9	65.9	62.8	50.6
65.7	65.5	1.0	65.9	67.0/67.2*	65.7	64.3	52.0
65.6	65.5	2.0	65.8	65.7/65.9*	65.8	63.7	53.8
65.7	65.5	4.0	66.6/84.3*	66.0/66.2*	66.2	64.2†	59.6
65.5	65.6	6.0	66.2/76.5*	63.3	67.2	67.1	60.2
65.6	65.4	7.0	-	-	66.3	-	-
65.7	65.5	8.0	-	-	-	65.1	63.3
65.6	65.7	9.0	65.1	-	-	-	-
65.8	65.8	17.0	65.8	-	-	-	-
65.7	65.3	18.0	-	66.7/66.3*	66.4	64.8	65.7
65.6	65.7	24.0	65.9/67.6*	66.4/66.4*	66.5	66.3	65.7
65.5	65.4	29.0	-	68.3	-	-	-
65.7	65.4						
65.5	65.4		17/4/78	28/4/78	26/5/78	8/9/78	1/5/79
65.6	65.5		t = 0.0	t = 0.0	t = 0.0	t = 2.0	t = 18.0
65.6	65.5		65.6	63.5	65.2	63.5	66.3
65.4	65.5		65.8	66.0	65.4	64.7	65.6
65.5	65.7		65.2	66.0	65.2	64.5	65.6
65.2	65.9		65.9	66.0	64.9	64.7	66.0
			65.9	66.0	65.5	64.7	65.9
			3/F/Q	3/F/Q	3/F/Q	3/F/Q	3/F/Q
			65.8	65.9	65.2	64.7	65.9
			65.8	66.0	62.4	64.3	65.8
			65.1	65.9	64.8	64.7	65.2
			65.8	66.1	65.2	64.8	67.2
			65.4	66.0	64.9	65.1	66.5

TABLE 23

SILICATE (UNFILTERED) #4
μg at L^{-1}

No Storage 30/3/78 4/NF/G		t thaw time (hours)	2 weeks 13/4/78 4/NF/R	1 month 25/4/78 4/NF/R	2 months 25/5/78 4/NF/R	5 months 5/9/78 4/NF/R	1 year 25/4/79 4/NF/R
98.6	98.9	0.0	13.2	12.1	8.3	4.5	4.0
98.6	99.0	0.5	15.9	19.8	8.9	9.2	5.3
99.0	99.2	1.0	31.1	28.1/22.0*	12.8	8.4	8.4
99.1	99.4	2.0	80.1	51.8/50.8*	56.9	16.8	40.6
98.3	99.4	4.0	98.7/53.9*	74.4/77.8*	50.5	22.3†	40.3
98.7	98.8	6.0	123.8/73.1*	66.1	83.9	52.4	50.5
99.2	98.7	7.0	-	-	69.2	-	-
99.1	98.9	8.0	-	-	-	57.7	56.7
98.6	99.2	9.0	64.0	-	-	-	-
98.7	98.6	17.0	60.3	-	-	-	-
98.4	99.5	18.0	-	67.0/63.4*	75.3	59.1	63.7
99.3	99.1	24.0	86.9/79.5*	82.9/86.6*	85.0	86.4	73.5
98.6	98.7	29.0	-	87.6	-	-	-
99.2	99.2						
98.9	99.1		17/4/78	28/4/78	26/5/78	8/9/78	1/5/79
99.6	99.2		t = 3.5	t = 24.0	t = 24.0	t = 24.0	t = 24.0
99.0	98.9		69.9	83.9	81.4	73.3	78.5
98.7	99.9		77.9	82.2	85.2	70.0	81.4
98.2	99.0		68.1	93.8	81.4	73.9	79.9
99.3	99.3		79.9	87.6	86.4	80.7	84.8
98.0	99.1		77.5	94.8	85.1	76.0	82.1
99.2	99.3						
99.1	99.6		4/NF/Q	4/NF/Q	4/NF/Q	4/NF/Q	4/NF/Q
99.8	98.7		71.5	90.2	86.3	83.6	88.4
98.6	99.2		74.0	92.8	87.5	82.4	88.8
			63.5	99.3	88.4	80.9	91.1
			73.9	93.4	86.0	84.2	90.6
			65.9	100.2	85.2	84.6	90.9

TABLE 24

SILICATE (FILTERED) #4
μg at L^{-1}

No Storage 30/3/78 4/F/G		t thaw time (hours)	2 weeks 13/4/78 4/F/R	1 month 25/4/78 4/F/R	2 months 25/5/78 4/F/R	5 months 5/9/78 4/F/R	1 year 25/4/79 4/F/R
98.2	98.7	0.0	10.8	14.8	8.9	2.9	3.1
97.4	98.0	0.5	24.5	25.9	11.0	5.7	4.6
97.8	98.2	1.0	49.5	20.0/30.9*	10.2	12.0	6.4
98.1	98.4	2.0	77.6	70.3/37.1*	21.4	16.7	20.8
97.5	97.8	4.0	93.5/34.7*	73.0/75.6*	76.1	22.9†	41.8
98.0	98.4	6.0	84.8/63.6*	82.8	69.8	52.8	42.7
97.7	97.9	7.0	–	–	–	–	–
98.1	97.8	8.0	–	–	–	67.4	51.6
98.3	97.8	9.0	77.3	–	–	–	–
98.2	97.8	17.0	71.6	–	–	–	–
97.7	97.7	18.0	–	84.7/71.3*	75.9	61.3	60.6
98.5	97.8	24.0	86.4/83.1*	93.4/88.0*	90.8	83.1	75.7
97.7	98.2	29.0	–	87.0	–	–	–
97.8	98.3						
98.0	98.2		17/4/78	28/4/78	26/5/78	8/9/73	1/5/79
97.7	97.7		t = 4.0	t = 24.0	t = 24.0	t = 24.0	t = 24.0
97.5	97.6		71.8	95.1	88.8	78.5	84.5
97.7	97.9		79.5	98.2	87.5	90.7	84.1
97.9	98.2		81.5	90.5	86.8	84.8	82.0
98.8	98.6		86.4	73.3	87.6	73.2	86.4
98.6			83.2	–	87.8	78.7	81.4
			4/F/Q	4/F/Q	4/F/Q	4/F/Q	4/F/Q
			71.4	86.8	87.6	85.0	90.4
			67.5	91.4	90.6	86.0	87.3
			73.8	92.7	91.6	84.6	87.9
			73.7	92.6	88.4	89.8	87.8
			71.6	–	–	–	89.2

TABLE N - 1

NITRATE

Summary of all $\bar{X} \pm s$

$$s^2 = \frac{\Sigma(X_i-\bar{X})^2}{n-1}$$

n = 5 for all groups except those determined on-board (no storage)

Sample	G No Storage	2w	1m	2m	5m	1y
1/NF/R	26.88 ± .1015	26.62 ± .0447	26.32 ± .0447	26.58 ± .0447	26.44 ± .1817	26.38 ± .2168
1/NF/Q	n = 17	26.64 ± .1140	26.44 ± .2191	26.63 ± .0433	26.40 ± .0707	26.62 ± .0837
1/F/R	26.66 ± .0945	26.38 ± .0837	26.42 ± .0447	26.68 ± .0837	26.44 ± .0894	26.60 ± .1732
1/F/Q	n = 20	26.54 ± .0548	26.42 ± .0837	26.62 ± .0447	26.30 ± .0158	26.60 ± .0158
2/NF/R	24.69 ± .1044	24.00 ± .2121	24.56 ± .2074	24.76 ± .0547	22.48 ± 2.040	23.70 ± .987
2/NF/Q	n = 21	24.78 ± .1304	24.70 ± .1225	24.52 ± .3194	23.38 ±1.907	24.58 ±1.026
2/F/R	24.83 ± .1261	24.68 ± .0447	24.60 ± .2345	24.88 ± .0837	24.36 ± .7092	23.82 ±1.148
2/F/Q	n = 20	24.74 ± .0894	24.70 ± .0158	24.88 ± .1923	24.72 ± .2280	24.88 ± .1089
3/NF/R	29.11 ± .1000	28.60 ± .3162	28.44 ± .3362	28.48 ± .4494	28.30 ± .5050	28.12 ± .9731
3/NF/Q	n = 20	28.94 ± .1140	28.48 ± .5263	28.78 ± .0447	28.28 ± .4087	28.84 ± .3782
3/F/R	29.45 ± .0761	28.96 ± .1342	28.66 ± .1342	28.66 ± .2702	28.18 ± .9960	28.88 ±1.092
3/F/Q	n = 20	28.58 ± .3962	28.64 ± .0894	28.06 ± .7369	28.42 ± .1789	29.18 ± .6058
4/NF/R	11.41 ± .0849	11.44 ± .1517	11.06 ± .2074	11.50 ± .0158	11.26 ± .4827	11.24 ± .0894
4/NF/Q	n = 51	11.40 ± .0158	11.22 ± .1304	11.88 ± .7530	12.86 ± 1.537	11.94 ± .3847
4/F/R	11.52 ± .0699	11.62 ± .0447	11.26 ± .0548	11.58 ± .0447	11.60 ± .0158	11.64 ± .0548
4/F/Q	n = 43	11.60 ± .0158	11.30 ± .1225	11.74 ± .3050	12.18 ± .6261	12.26 ± .8620

TABLE P - 1

PHOSPHATE

Summary of all $\bar{X} \pm s$

$$s^2 = \frac{\Sigma(X_i - \bar{X})^2}{n-1}$$

n = 5 for all groups except those determined on-board (no storage)

Sample	G No Storage	2w	1m	2m	5m	1y
1/NF/R	2.404 ± .0067	2.392 ± .0217	2.262 ± .0934	2.370 ± .0187	2.376 ± .0695	2.222 ± .0536
1/NF/Q	n = 11	2.360 ± .0016	2.354 ± .0055	2.368 ± .0110	2.456 ± .0089	2.462 ± .0045
1/F/R	2.398 ± .0088	2.334 ± .0241	2.340 ± .1883	2.354 ± .0288	2.418 ± .0602	2.370 ± .1168
1/F/Q	n = 17	2.374 ± .0055	2.364 ± .0055	2.406 ± .0114	2.486 ± .0089	2.482 ± .0130
2/NF/R	2.257 ± .0109	2.182 ± .0278	2.178 ± .0471	2.194 ± .0182	2.192 ± .1482	2.080 ± .1655
2/NF/Q	n = 20	2.244 ± .0055	2.202 ± .0217	2.196 ± .0551	2.078 ± .1956	2.214 ± .0764
2/F/R	2.225 ± .0209	2.224 ± .0167	2.158 ± .0164	2.220 ± .0283	2.248 ± .0415	2.020 ± .0963
2/F/Q	n = 20	2.218 ± .0045	2.190 ± .0016	2.252 ± .0084	2.320 ± .0303	2.270 ± .0396
3/NF/R	2.783 ± .0658	2.788 ± .0228	2.690 ± .0412	2.612 ± .0217	2.774 ± .1464	2.792 ± .0870
3/NF/Q	n = 20	2.788 ± .0083	2.646 ± .1683	2.752 ± .0691	2.890 ± .0346	2.802 ± .1011
3/F/R	2.802 ± .0077	2.744 ± .0321	2.750 ± .0447	2.422 ± .3828	2.474 ± .3660	2.664 ± .3314
3/F/Q	n = 19	2.656 ± .0594	2.730 ± .0400	2.734 ± .0467	2.780 ± .1428	2.442 ± .2775
4/NF/R	0.956 ± .0456	0.678 ± .0563	0.936 ± .0586	0.762 ± .0712	0.798 ± .0646	0.796 ± .0230
4/NF/Q	n = 40	1.086 ± .0230	1.072 ± .0492	1.052 ± .0164	1.050 ± .0179	1.110 ± .0200
4/F/R	0.300 ± .0082	0.326 ± .0114	0.294 ± .0089	0.284 ± .0055	0.312 ± .0268	0.316 ± .0250
4/F/Q	n = 38	0.320 ± .0071	0.292 ± .0045	0.300 ± .0224	0.304 ± .0089	0.308 ± .0130

TABLE Si - 1

SILICATE

Summary of all $\bar{X} \pm s$

$$s^2 = \frac{\Sigma(X_i - \bar{X})^2}{n-1}$$

n = 5 for all groups except those determined on-board (no storage)

Sample	G No Storage	2w	1m	2m	5m	1y
1/NF/R	54.10 ± 0.100	52.72 ± 0.164	53.42 ± 0.795	52.90 ± 0.283	52.00 ± 0.200	53.24 ± 0.856
1/NF/Q	n = 19	52.60 ± 0.173	53.90 ± 0.235	53.14 ± 0.182	52.74 ± 0.167	54.30 ± 0.292
1/F/R	54.01 ± 0.157	57.62 ± 3.757	53.78 ± 0.178	53.08 ± 0.383	52.94 ± 1.009	52.56 ± 3.088
1/F/Q	n = 20	54.10 ± 1.373	53.72 ± 0.110	53.00 ± 0.187	52.78 ± 0.363	54.36 ± 0.673
2/NF/R	54.21 ± 0.089	54.60 ± 0.406	54.28 ± 0.606	53.52 ± 0.110	55.32 ± 0.756	54.58 ± 0.680
2/NF/Q	n = 21	54.28 ± 0.427	53.78 ± 0.598	53.56 ± 0.182	55.96 ± 0.297	53.14 ± 1.913
2/F/R	54.20 ± 0.083	53.78 ± 0.249	54.28 ± 0.179	50.66 ± 4.399	53.30 ± 0.682	52.68 ± 1.921
2/F/Q	n = 20	53.66 ± 0.152	54.52 ± 0.402	53.90 ± 0.815	52.16 ± 0.483	53.12 ± 0.228
3/NF/R	65.73 ± 0.087	65.48 ± 0.110	65.88 ± 0.303	65.08 ± 0.303	64.68 ± 0.130	66.14 ± 0.428
3/NF/Q	n = 20	65.52 ± 0.130	65.96 ± 0.288	65.00 ± 0.815	64.30 ± 1.492	66.40 ± 1.492
3/F/R	65.59 ± 0.130	65.68 ± 0.295	65.88 ± 0.268	65.24 ± 0.230	64.42 ± 0.522	65.88 ± 0.295
3/F/Q	n = 20	65.58 ± 0.319	65.98 ± 0.084	65.0 ± 0.179	64.72 ± 0.286	66.12 ± 0.760
4/NF/R	98.99 ± 0.393	74.66 ± 5.285	88.46 ± 5.688	83.90 ± 2.339	74.78 ± 3.948	81.34 ± 2.382
4/NF/Q	n = 50	69.76 ± 4.802	95.18 ± 4.353	86.76 ± 1.226	83.14 ± 1.503	89.90 ± 1.212
4/F/R	98.01 ± 0.347	80.49 ± 5.470	92.84 ± 4.293	87.70 ± 0.721	81.18 ± 6.722	83.68 ± 2.017
4/F/Q	n = 41	71.60 ± 2.554	90.86 ± 2.407	89.54 ± 1.615	86.36 ± 2.056	88.52 ± 1.264

TABLE N - 2

NITRATE

Wilson's non-parametric ANOVA (four-way with equal replication)

Factor A - Filtering (2 Levels: F, NF)

Factor B - Freezing (2 Levels: Q, R)

Factor C - Time (5 Levels: 2w, 1m, 2m, 5m, 1y)

Factor D - Sample (4 Levels: 1, 2, 3, 4)

H_o: there is no effect * - Significant ($\alpha = 0.05$)

H_a: there is an effect ** - Highly Significant ($\alpha = 0.01$)

χ^2 test statistic	DF	Factor	Conclusion
0.00	1	A	Accept H_o
0.00	1	B	Accept H_o
0.10	4	C	Accept H_o
392.08	3	D	Reject H_o**
1.42	12	Total Interaction	Accept H_o
Σ 393.6	79		

TABLE P - 2

PHOSPHATE

Wilson's non-parametric ANOVA (four-way with equal replication)

Factor A - Filtering (2 Levels: F,NF)

Factor B - Freezing (2 Levels: Q, R)

Factor C - Time (5 Levels: 2w, 1m, 2m, 5m, 1y)

Factor D - Sample (4 Levels: 1, 2, 3, 4)

H_o: there is no effect * - Significant ($\alpha = 0.05$)

H_a: there is an effect ** - Highly Significant ($\alpha = 0.01$)

χ^2 test statistic	DF	Factor	Conclusion
0.09	1	A	Accept H_o
2.25	1	B	Accept H_o
3.56	4	C	Accept H_o
303.94	3	D	Reject H_o**
34.14	12	Total Interaction	Reject H_o**
Σ 343.99	79		

TABLE Si - 2

SILICATE

Wilson's non-parametric ANOVA (four-way with equal replication)

Factor A - Filtering (2 Levels: F, NF)

Factor B - Freezing (2Levels: Q, R)

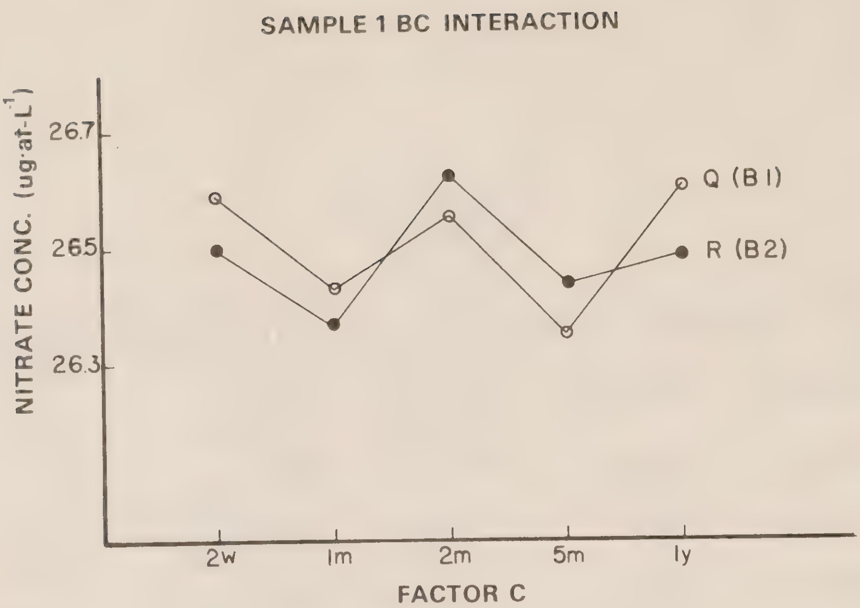
Factor C - Time (5 Levels: 2w, 1m, 2m, 5m, 1y)

Factor D - Sample (4 Levels: 1, 2, 3, 4)

H_o: there is no effect * - Significant (α = 0.05)

H_o: there is an effect ** - Highly Significant (α = 0.01)

	χ^2 test statistic	DF	Factor	Conclusion
	0.01	1	A	Accept H_o
	0.01	1	B	Accept H_o
	0.04	4	C	Accept H_o
	388.12	3	D	Reject H_o**
	2.22	12	Total interaction	Accept H_o
Σ	390.40	79		


SAMPLE 1 BC INTERACTION
NITRATE CONC. (ug·at·L⁻¹)
26.7
26.5
26.3
Q (B1)
R (B2)
2w
1m
2m
5m
1y
FACTOR C

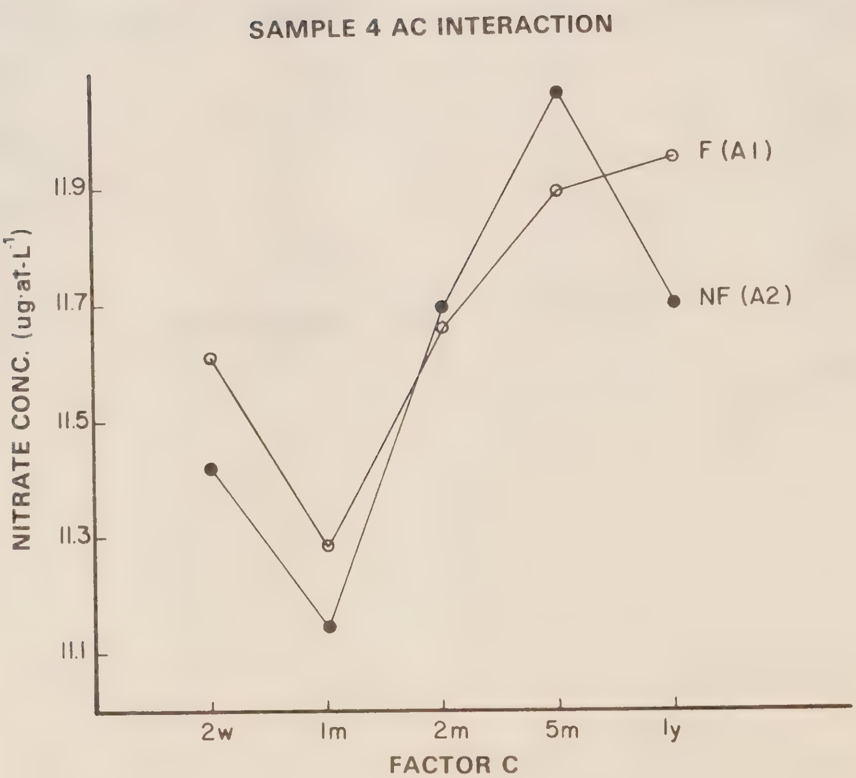

SAMPLE 4 AC INTERACTION
NITRATE CONC. (ug·at·L⁻¹)
11.9
11.7
11.5
11.3
11.1
F (A1)
NF (A2)
2w
1m
2m
5m
1y
FACTOR C

TABLE N - 3

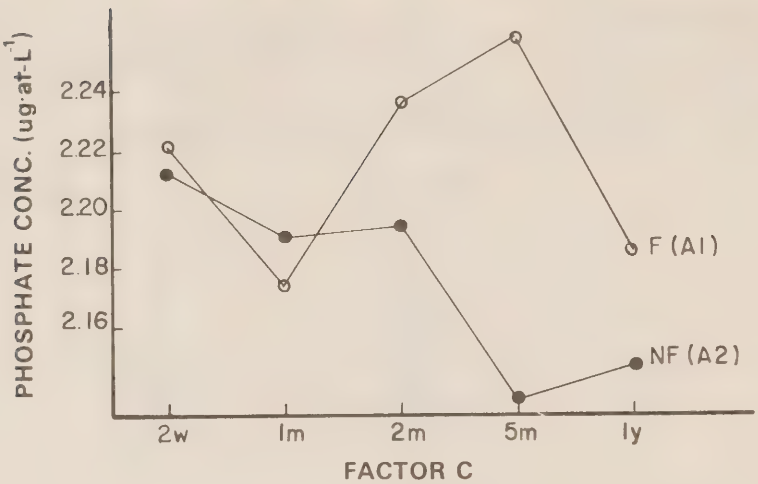
NITRATE

Wilson's non-parametric ANOVA (three-way with equal replication)
Factor A - Filtering (2 Levels: F, NF)
Factor B - Freezing (2 Levels: Q, R)
Factor C - Time (5 Levels: 2w, 1m, 2m, 5m, 1y)

H_o - there is no effect * - Significant ($\alpha = 0.05$)
H_a - there is an effect ** - Highly Significant ($\alpha = 0.01$)

χ^2 test statistic	DF	Probability	Factor	Conclusion
		Sample 1		
.04	1	0.836	A	Accept H_o
1.07	1	0.300	B	Accept H_o
32.86	4	0.000	C	Reject H_o**
.04	1	0.836	AB	Accept H_o
4.89	4	0.299	AC	Accept H_o
13.30	4	0.010	BC	Reject H_o**
4.89	4	0.299	ABC	Accept H_o
		Sample 2		
8.05	1	0.005	A	Reject H_o**
5.91	1	0.015	B	Reject H_o*
16.67	4	0.002	C	Reject H_o**
0.00	1	0.999	AB	Accept H_o
0.57	4	0.966	AC	Accept H_o
8.46	4	0.076	BC	Accept H_o
7.80	4	0.099	ABC	Accept H_o
		Sample 3		
0.16	1	0.689	A	Accept H_o
0.16	1	0.689	B	Accept H_o
20.80	4	0.000	C	Reject H_o**
1.44	1	0.230	AB	Accept H_o
2.24	4	0.692	AC	Accept H_o
5.44	4	0.245	BC	Accept H_o
7.36	4	0.118	ABC	Accept H_o
		Sample 4		
9.89	1	0.002	A	Reject H_o**
0.04	1	0.834	B	Accept H_o
54.95	4	0.000	C	Reject H_o**
0.04	1	0.834	AB	Accept H_o
10.98	4	0.027	AC	Reject H_o*
1.49	4	0.828	BC	Accept H_o
1.49	4	0.828	ABC	Accept H_o

SAMPLE 2 AC INTERACTION



SAMPLE 3 BC INTERACTION

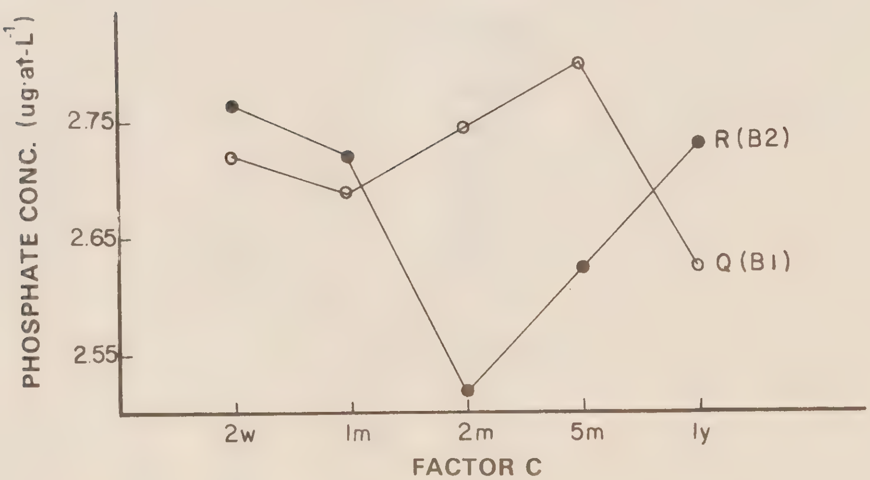


TABLE P - 3

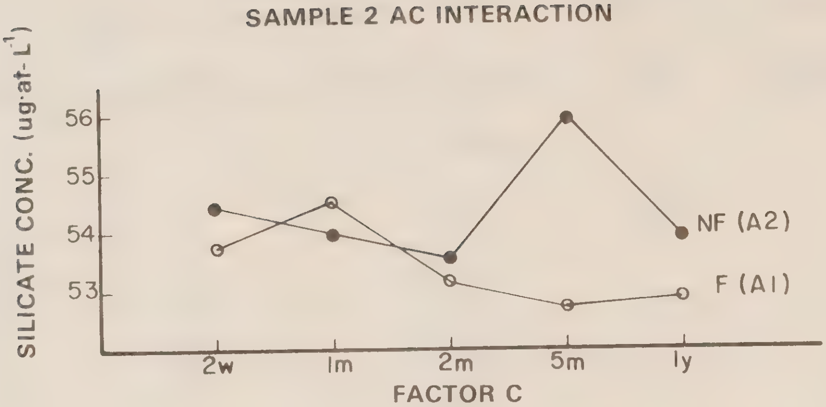
PHOSPHATE

Wilson's non-parametric ANOVA (three-way with equal replication)
Factor A - Filtering (2 Levels: F, NF)
Factor B - Freezing (2 Levels: Q, R)
Factor C - Time (5 Levels: 2w, 1m, 2m, 5m, 1y)

H_o - there is no effect * - Significant ($\alpha = 0.05$)
H_a - there is an effect ** - Highly Significant ($\alpha = 0.01$)

χ^2 test statistic	DF	Probability	Factor	Conclusion
		Sample 1		
2.60	1	0.107	A	Accept H_o
10.39	1	0.001	B	Reject H_o**
20.04	4	0.000	C	Reject H_o**
2.60	1	0.107	AB	Accept H_o
1.87	4	0.760	AC	Accept H_o
6.25	4	0.181	BC	Accept H_o
18.91	4	0.001	ABC	Reject H_o**
		Sample 2		
1.44	1	0.230	A	Accept H_o
10.26	1	0.001	B	Reject H_o**
11.06	4	0.026	C	Reject H_o*
0.16	1	0.689	AB	Accept H_o
10.58	4	0.032	AC	Reject H_o*
4.97	4	0.290	BC	Accept H_o
2.24	4	0.691	ABC	Accept H_o
		Sample 3		
4.01	1	0.045	A	Reject H_o*
4.01	1	0.045	B	Reject H_o*
5.45	4	0.244	C	Accept H_o
0.64	1	0.423	AB	Accept H_o
7.21	4	0.125	AC	Accept H_o
15.22	4	0.004	BC	Reject H_o**
2.56	4	0.633	ABC	Accept H_o
		Sample 4		
100.00	1	0.000	A	Reject H_o**
0.00	1	1.000	B	Accept H_o
0.00	4	1.000	C	Accept H_o
0.00	1	1.000	AB	Accept H_o
0.00	4	1.000	AC	Accept H_o
0.00	4	1.000	BC	Accept H_o
0.00	4	1.000	ABC	Accept H_o

SAMPLE 2 AC INTERACTION



SAMPLE 4 BC INTERACTION

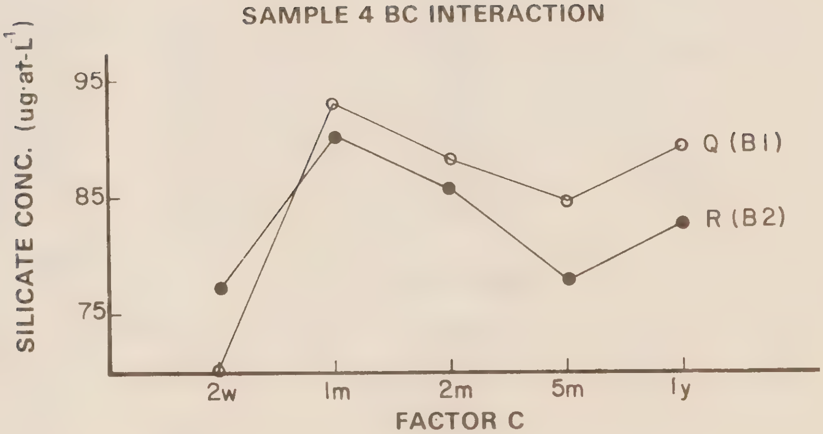


TABLE Si - 3

SILICATE

Wilson's non-parametric ANOVA (three-way with equal replication)
Factor A - Filtering (2 Levels: F, NF)
Factor B - Freezing (2 Levels: Q, R)
Factor C - Time (5 Levels: 2w, 1m, 2m, 5m, 1y)

H_o - there is no effect   * - Significant ($\alpha = 0.05$)
H_a - there is an effect   ** - Highly Significant ($\alpha = 0.01$)

χ^2 test statistic	DF	Probability	Factor	Conclusion
		Sample 1		
4.86	1	0.027	A	Reject H_o*
1.97	1	0.161	B	Accept H_o
34.77	4	0.000	C	Reject H_o**
1.97	1	0.161	AB	Accept H_o
9.39	4	0.052	AC	Accept H_o
3.45	4	0.485	BC	Accept H_o
3.45	4	0.485	ABC	Accept H_o
		Sample 2		
4.89	1	0.027	A	Reject H_o*
4.89	1	0.027	B	Reject H_o*
18.99	4	0.001	C	Reject H_o**
0.04	1	0.841	AB	Accept H_o
19.15	4	0.001	AC	Reject H_o**
5.41	4	0.247	BC	Accept H_o
2.99	4	0.559	ABC	Accept H_o
		Sample 3		
0.00	1	1.000	A	Accept H_o
0.00	1	1.000	B	Accept H_o
59.20	4	0.000	C	Reject H_o**
0.16	1	0.689	AB	Accept H_o
1.60	4	0.809	AC	Accept H_o
2.40	4	0.663	BC	Accept H_o
1.43	4	0.837	ABC	Accept H_o
		Sample 4		
4.84	1	0.028	A	Reject H_o*
9.00	1	0.003	B	Reject H_o**
46.17	4	0.000	C	Reject H_o**
1.00	1	0.317	AB	Accept H_o
1.36	4	0.851	AC	Accept H_o
10.80	4	0.029	BC	Reject H_o*
2.80	4	0.592	ABC	Accept H_o

TABLE N - 4

NITRATE

Wilson's non-parametric ANOVA (one-way with equal replication) comparing 11 groups (on-board analysis, Q stored samples (5 dates) and R stored samples (5 dates)).

H_o: $\mu_1 = \mu_2 = \ldots = \mu_{11}$ * Significant ($\alpha = 0.05$)

$\alpha = 0.05$ ** Highly Significant ($\alpha = 0.01$)

Sample	χ^2 test statistic	DF	Probability	Conclusion
1/NF	41.35	10	0.000	Reject H_o**
1/F	51.67	10	0.000	Reject H_o**
2/NF	35.59	10	0.000	Reject H_o**
2/F	29.87	10	0.001	Reject H_o**
3/NF	47.58	10	0.000	Reject H_o**
3/F	46.00	10	0.000	Reject H_o**
4/NF	27.89	10	0.002	Reject H_o**
4/F	43.75	10	0.000	Reject H_o**

TABLE P - 4

PHOSPHATE

Wilson's non-parametric ANOVA (one-way with equal replication) comparing 11 groups (on-board analysis, Q stored samples (5 dates) and R stored samples (5 dates)).

H_o: $\mu_1 = \mu_2 = \ldots = \mu_{11}$ * Significant ($\alpha = 0.05$)

$\alpha = 0.05$ ** Highly Significant ($\alpha = 0.01$)

Sample	χ^2 test statistic	DF	Probability	Conclusion
1/NF	45.00	10	0.000	Reject H_o**
1/F	41.07	10	0.000	Reject H_o**
2/NF	44.38	10	0.000	Reject H_o**
2/F	28.85	10	0.001	Reject H_o**
3/NF	25.67	10	0.004	Reject H_o**
3/F	36.94	10	0.000	Reject H_o**
4/NF	40.48	10	0.000	Reject H_o**
4/F	38.43	10	0.000	Reject H_o**

TABLE Si - 4

SILICATE

Wilson's non-parametric ANOVA (one-way with equal replication) comparing 11 groups (on-board analysis, Q stored samples (5 dates) and R stored samples (5 dates)).

H_o: $\mu_1 = \mu_2 = \ldots = \mu_{11}$ * Significant (α = 0.05)

α = 0.05   ** Highly Significant (α = 0.01)

Sample	χ^2 test statistic	DF	Probability	Conclusion
1/NF	54.52	10	0.000	Reject H_o**
1/F	33.52	10	0.000	Reject H_o**
2/NF	25.98	10	0.004	Reject H_o**
2/F	50.74	10	0.000	Reject H_o**
3/NF	47.65	10	0.000	Reject H_o**
3/F	39.99	10	0.000	Reject H_o**
4/NF	87.52	10	0.000	Reject H_o**
4/F	81.40	10	0.000	Reject H_o**

TABLE N - 5

NITRATE

Non-parametric comparison of the on-board analysis (control) to the stored groups. Equal replication (5) was generated by selecting 5 of the on-board determinations at random.

$$SE = \sqrt{\frac{n(np)(np+1)}{6}} \qquad q_{test} = \frac{\sum_{control} \text{ranks} - \sum_{group} \text{ranks}}{SE}$$

Two tailed hypothesis H_o: $\mu_{control} = \mu_{group}$
$\alpha = 0.05$

Sample Ordered Rank Sums: Bars are drawn where H_o is Rejected.

Sample												
1/NF	Group	G	Q/2w	R/2w	Q/1y	R/2m	Q/2m	R/5m	Q/1m	R/1y	Q/5m	R/1m
	$\bar{X}$	26.88	26.64	26.62	26.62	26.58	26.50	26.44	26.44	26.38	26.40	26.32
1/F	Group	G	R/2m	Q/2m	R/1y	Q/1y	Q/2w	R/5m	R/1m	Q/1m	R/2w	Q/5m
	$\bar{X}$	26.66	26.68	26.62	26.60	26.60	26.42	26.44	26.42	26.42	26.38	26.30
2/NF	Group	R/2m	Q/2w	Q/1m	G	Q/2m	R/1m	Q/1y	Q/5m	R/1y	R/2w	R/5m
	$\bar{X}$	24.76	24.78	24.70	24.69	24.52	24.56	24.58	23.38	23.70	24.00	22.48
2/F	Group	G	R/2m	Q/2m	Q/1y	Q/2w	Q/5m	Q/1m	R/2w	R/1m	R/5m	R/1y
	$\bar{X}$	24.83	24.88	24.88	24.62	24.74	24.72	24.70	24.68	24.60	24.36	23.82
3/NF	Group	G	Q/2w	Q/2m	Q/1y	R/2w	R/2m	Q/1m	R/1m	R/5m	R/1y	Q/5m
	$\bar{X}$	29.11	28.94	28.78	28.84	28.60	28.48	28.48	28.44	28.30	28.12	28.28
3/F	Group	G	R/2w	Q/1y	R/2m	R/1y	Q/2w	Q/1m	R/1m	R/5m	Q/5m	Q/2m
	$\bar{X}$	29.45	28.96	29.18	28.66	28.88	28.58	28.64	28.66	28.18	28.42	28.06
4/NF	Group	Q/1y	Q/5m	Q/2m	R/2m	R/1y	R/5m	R/2w	G	Q/2w	Q/1m	R/1m
	$\bar{X}$	11.94	12.86	11.88	11.50	11.44	11.26	11.44	11.41	11.40	11.22	11.06
4/F	Group	Q/5m	Q/1y	R/1y	R/2w	Q/2m	Q/2w	R/5m	R/2m	G	Q/1m	R/1m
	$\bar{X}$	12.18	12.26	11.64	11.62	11.74	11.60	11.60	11.58	11.52	11.30	11.26

TABLE P - 5

PHOSPHATE

Non-parametric comparison of the on-board analysis (control) to the stored groups. Equal replication (5) was generated by selecting 5 of the on-board determinations at random.

$$SE = \sqrt{\frac{n(np)(np+1)}{6}} \qquad q_{test} = \frac{\sum_{control} ranks - \sum_{group} ranks}{SE}$$

Two tailed hypothesis H_o: $\mu_{control} = \mu_{group}$

$\alpha = 0.05$

Sample Ordered Rank Sums: Bars are drawn where H_o is rejected.

Sample												
1/NF	Group	Q/1y	Q/5m	G	R/2w	R/5m	Q/2m	R/2m	Q/2w	Q/1m	R/1m	R/1y
	$\bar{X}$	2.462	2.456	2.404	2.392	2.376	2.368	2.370	2.360	2.354	2.262	2.222
1/F	Group	Q/5m	Q/1y	Q/2m	R/5m	G	R/1y	Q/2w	Q/1m	R/1m	R/2m	R/2w
	$\bar{X}$	2.486	2.482	2.406	2.418	2.398	2.370	2.374	2.364	2.384	2.354	2.334
2/NF	Group	G	Q/2w	Q/1y	R/5m	Q/2m	Q/1m	R/2m	Q/5m	R/1m	R/2w	R/1y
	$\bar{X}$	2.257	2.244	2.214	2.192	2.196	2.202	2.194	2.078	2.178	2.182	2.080
2/F	Group	Q/2m	Q/5m	R/5m	Q/1y	R/2w	R/2m	Q/2w	G	Q/1m	R/1y	R/1m
	$\bar{X}$	2.252	2.224	2.248	2.224	2.224	2.220	2.218	2.224	2.190	2.148	2.158
3/NF	Group	Q/5m	G	Q/1y	R/1y	R/2w	Q/2w	R/5m	Q/2m	R/1m	Q/1m	R/2m
	$\bar{X}$	2.818	2.783	2.802	2.792	2.788	2.788	2.774	2.752	2.690	2.646	2.612
3/F	Group	G	Q/5m	R/2w	R/1y	R/1m	Q/1m	Q/2m	R/5m	Q/2w	Q/1y	R/2m
	$\bar{X}$	2.802	2.780	2.744	2.664	2.750	2.730	2.734	2.474	2.656	2.442	2.422
4/NF	Group	Q/1y	Q/2w	Q/1m	Q/2m	Q/5m	G	R/1m	R/5m	R/1y	R/2m	R/2w
	$\bar{X}$	1.110	1.086	1.072	1.052	0.992	0.956	0.936	0.858	0.796	0.762	0.678
4/F	Group	R/2w	Q/2w	R/1y	Q/1y	R/5m	Q/5m	G	Q/2m	R/1m	Q/1m	R/2m
	$\bar{X}$	0.320	0.326	0.308	0.316	0.312	0.304	0.300	0.300	0.294	0.292	0.284

TABLE Si - 5

SILICATE

Non-parametric comparison of the on-board analysis (control) to the stored groups. Equal replication (5) was generated by selecting 5 of the on-board determinations at random.

$$SE = \sqrt{\frac{n(np)(np+1)}{6}} \qquad q_{test} = \frac{\sum_{control} ranks - \sum_{group} ranks}{SE}$$

Two tailed hypothesis H_o: $\mu_{control} = \mu_{group}$

$\alpha = 0.05$

Sample Ordered rank sums: Bars are drawn where H_o is rejected

Sample												
1/NF	Group	| Q/1y	G	| Q/1m	R/1m	Q/2m	R/1y	R/2m	Q/5m	R/2w	Q/2w	R/5m
	$\bar{X}$	| 54.30	54.10	| 53.90	53.42	53.14	53.24	52.90	52.74	52.72	52.60	52.00
1/F	Group	R/2w	Q/1y	| G	R/1m	Q/2w	Q/1m	R/1y	| Q/2m	R/2m	R/5m	Q/5m
	$\bar{X}$	57.62	54.36	| 54.01	53.88	54.10	53.72	52.56	| 53.00	52.94	52.94	52.78
2/NF	Group	R/5m	Q/5m	| R/2w	R/1y	R/1m	Q/2w	G	| Q/1y	Q/1m	Q/2m	R/2m
	$\bar{X}$	56.76	55.20	| 54.60	54.58	54.28	54.28	54.21	| 53.14	53.78	53.66	53.52
2/F	Group	R/1m	Q/1m	| G	Q/2m	| R/2w	Q/2w	R/1y	R/5m	Q/1y	R/2m	Q/5m
	$\bar{X}$	54.48	54.52	| 54.20	55.70	| 53.78	53.66	52.68	53.30	53.12	50.66	52.16
3/NF	Group	| R/1m	R/1y	Q/1m	Q/1y	G	| R/2w	Q/2w	Q/2m	R/2m	Q/5m	R/5m
	$\bar{X}$	| 65.96	66.40	66.52	66.14	65.73	| 65.28	65.48	65.00	65.08	64.30	64.68
3/F	Group	Q/1m	| R/1m	Q/1y	R/1y	R/2w	G	Q/2w	| R/2m	Q/2m	Q/5m	R/5m
	$\bar{X}$	65.98	| 65.50	66.12	65.88	65.68	65.59	65.58	| 65.24	64.50	64.72	64.42
4/NF	Group	G	Q/1m	| Q/1y	R/1m	Q/2m	R/2m	Q/5m	R/1y	R/5m	R/2w	Q/2w
	$\bar{X}$	98.99	95.18	| 89.90	88.46	86.76	83.90	83.14	81.34	74.78	69.76	74.66
4/F	Group	G	| R/1m	Q/1m	Q/2m	Q/1y	R/2m	Q/5m	R/5m	R/1y	R/2w	Q/2w
	$\bar{X}$	98.01	| 92.84	90.88	89.54	88.52	87.70	86.36	81.18	83.68	80.49	71.60

TABLE N - 6

NITRATE

(a) Two-tailed paired-sample t-test (testing for difference between samples thawed in the light and in the dark)

H_o : $\mu_d = 0$
H_a : $\mu_d \neq 0$
α = 0.05

$$\bar{d} = \overline{(X_L - X_D)} = -0.06034$$

$$s_{\bar{d}} = 0.0898$$

$$n = 59$$

$$t = \frac{\bar{d}}{s_{\bar{d}}} = -0.672$$

$$t_{.05(2),58} = 2.002$$

Conclusion: Accept H_o. There is no difference between samples thawed in the light and in the dark.

(b) Two-tailed paired-sample t-test (testing for difference between s_Q and s_R, the standard deviations of the Q and R groups respectively).

H_o : $\mu_d = 0$
H_a : $\mu_d \neq 0$
α = 0.05

$$\bar{d} = \overline{(s_Q - s_R)} = -0.03160$$

$$s_{\bar{d}} = 0.06949$$

$$n = 40$$

$$t = \frac{\bar{d}}{s_{\bar{d}}} = -0.455$$

$$t_{.05(2),39} = 2.023$$

Conclusion: Accept H_o. There is no difference between s_Q and s_R.

TABLE P - 6

PHOSPHATE

(a) Two-tailed paired-sample t-test (testing for difference between samples thawed in the light and in the dark.

H_o : $\mu_d = 0$

H_a : $\mu_d \neq 0$

α = 0.05

$$\bar{d} = \overline{(X_L - X_D)} = -0.01519$$

$$s_{\bar{d}} = 0.01768$$

$$n = 52$$

$$t = \frac{\bar{d}}{s_{\bar{d}}} = -0.859$$

$$t_{.05(2),51} = 2.007$$

Conclusion: Accept H_o. There is no difference between samples thawed in the light and in the dark.

(b) Two-tailed paired-sample t-test (testing for difference between s_Q and s_R , the standard deviation of the Q and R groups respectively).

H_o : $\mu_d = 0$

H_a : $\mu_d \neq 0$

α = 0.05

* - Significant ($\alpha = 0.05$)
** - Highly significant ($\alpha = 0.01$)

$$\bar{d} = \overline{(s_Q - s_R)} = -0.03567$$

$$S_{\bar{d}} = 0.01275$$

$$n = 40$$

$$t = \frac{\bar{d}}{s_{\bar{d}}} = -2.798$$

$$t_{.05(2),39} = 2.023$$

Conclusion: Reject H_o**. There is a difference between s_Q and s_R, s_R is higher than s_Q.

TABLE Si - 6

SILICATE

(a) Two-tailed paired-sample t-test (testing for difference between samples thawed in the light and in the dark).

H_o : $\mu_d = 0$

H_a : $\mu_d \neq 0$

$\alpha = 0.05$

$$\bar{d} = \overline{(X_L - X_D)} = -0.5854$$

$$s_{\bar{d}} = 0.5432$$

$$n = 48$$

$$t = \frac{\bar{d}}{s_{\bar{d}}} = -1.078$$

$$t_{.05(2),47} = 2.012$$

Conclusion: Accept H_o. There is no difference between samples thawed in the light and in the dark.

(b) Two-tailed paired-sample t-test (testing for difference between s_Q and s_R, the standard deviation of the Q and R groups respectively).

H_o : $\mu_d = 0$

H_a : $\mu_d \neq 0$

$\alpha = 0.05$

$$\bar{d} = \overline{(s_Q - s_R)} = 0.3366$$

$$s_{\bar{d}} = 0.1780$$

$$n = 38$$

$$t = \frac{\bar{d}}{s_{\bar{d}}} = 1.891$$

$$t_{.05(2),37} = 2.026$$

Conclusion: Accept H_o. There is no difference between s_Q and s_R.

TABLE 25

SAMPLE #1

Station 1: Sand heads (90 m), 49^0 06.3'N 123^0 19.5'W
Date: 28/3/78, 1850
Sample Depth: 20 m
Temperature: 7.92^{0}C
0_2: 5.80 mL L^{-1}
Salinity: 29.34 ^{o}/oo
Particulates: 0.075 ppmv

SAMPLE #2

Station 2: (348 m), 49^0 47.5'N 124^0 47.0'W
Date: 29/3/78, 1000
Sample Depth: 1 m
Temperature: 8.21^{0}C
0_2: 6.86 mL L^{-1}
Salinity: 28.81 ^{o}/oo
Particulates: 0.066 ppmv

SAMPLE #3

Station 2: (348 m), 49^0 47.5'N 124^0 47.0'W
Date: 29/3/78, 1550
Sample Depth: 300 m
Temperature: 9.14^{0}C
0_2: 3.23 mL L^{-1}
Salinity: 30.77 ^{o}/oo
Particulates: 0.050 ppmv

SAMPLE #4

Station 1A: Steveston (14 m) 49^0 06.9'N 123^0 11.27'W
Date: 30/3/78, 0926
Sample Depth: 0 m
Temperature: 7.2^{0}C
0_2: 8.77 mL L^{-1}
Salinity: 1.05 ^{o}/oo
Particulates: 0.186 ppmv

TABLE 26

Rejection of data based on Chauvenet's criterion. (Probability of observing such a large deviation from the mean in a group of n replicates is not greater than $\frac{1}{2n}$)

Nitrate

	2 w	1m	2m	5m	1y	Σ
R	1	0	3	3	4	11
Q	1	0	1	0	1	3
Σ	2	0	4	3	5	14

Phosphate

	2 w	1m	2m	5m	1y	Σ
R	0	0	1	0	3	4
Q	0	0	0	4	1	5
Σ	0	0	1	4	4	9

Silicate

	2 w	1m	2m	5m	1y	Σ
R	0	5	1	2	0	8
Q	2	0	4	1	0	7
Σ	2	5	5	3	0	15

TABLE 27

Bartlett's Test for Homogeneity of Variances

$H_o: \sigma_1^2 = \sigma_2^2 = \ldots \sigma_n^2$

* - Significant $\alpha = 0.05$ $\chi^2_{0.05,19} = 30.14$

** - Highly Significant $\alpha = 0.01$ $\chi^2_{0.01,19} = 36.19$

Sample	Nutrient	Test Statistic	Conclusion
1	Nitrate	72.12	Reject H_o**
2	"	165.56	Reject H_o**
3	"	72.89	Reject H_o**
4	"	200.59	Reject H_o**
1	Phosphate	159.30	Reject H_o**
2	"	155.15	Reject H_o**
3	"	112.66	Reject H_o**
4	"	132.41	Reject H_o**
1	Silicate	153.03	Reject H_o**
2	"	166.48	Reject H_o**
3	"	80.55	Reject H_o**
4	"	46.56	Reject H_o**

TABLE 28

Comparison of the first set of on-board determinations with the second set determined approximately one hour apart. Students t-test (two tailed) for difference between two means was used

H_o: $\bar{X}_1 = \bar{X}_2$, $\alpha(2) = 0.05$

* - Significant ($\alpha = 0.05$)
** - Highly Significant ($\alpha = 0.01$)

Nutrient	Sample	t_{calc}	t_{crit}	Conclusion	Percent Deviation $\frac{\bar{X}_1 - \bar{X}_2}{\bar{X}_1} \times 100$	$\frac{2s}{\bar{X}}$
Nitrate	1/NF	14.89	2.030	Reject H_o**	1.66	0.19
	1/F	6.66	2.024	Reject H_o**	0.60	0.18
	2/NF	-5.47	2.028	Reject H_o**	-0.66	0.21
	2/F	-1.72	2.023	Accept H_o	-0.36	0.25
	3/NF	-15.68	2.024	Reject H_o**	-1.51	0.18
	3/F	19.12	2.037	Reject H_o**	1.82	0.13
Phosphate	1/NF	-1.27	2.045	Accept H_o	-0.14	0.56
	1/F	-5.47	2.030	Reject H_o**	-0.55	0.18
	2/NF	2.85	2.026	Reject H_o**	1.08	0.24
	2/F	-0.27	2.023	Accept H_o	-0.10	0.47
	3/NF	-2.94	2.024	Reject H_o**	-1.56	1.18
	3/F	-2.38	2.035	Reject H_o*	-0.26	0.14
Silicate	1/NF	2.86	2.026	Reject H_o**	0.25	0.09
	1/F	9.90	2.024	Reject H_o**	0.95	0.15
	2/NF	-1.15	2.023	Accept H_o	-0.06	0.08
	2/F	-6.77	2.023	Reject H_o**	-0.34	0.08
	3/NF	11.70	2.024	Reject H_o**	0.50	0.07
	3/F	0.92	2.024	Accept H_o	0.06	0.10

TABLE 29

Comparison of filtered and not filtered on-board determinations

H_o: there is no effect due to filtering
$\alpha = 0.05$

* - Significant ($\alpha = 0.05$)
** - Highly Significant ($\alpha = 0.01$)

Sample #	Nutrient	$t_{0.05(2),\ DF}$	t	Conclusion	$\frac{\bar{X}_{NF} - \bar{X}_F}{\bar{X}_{NF}} \times 100$
1	Nitrate	2.030	6.82	Reject H_o**	0.82
2	"	2.023	-3.88	Reject H_o**	-0.57
3	"	2.024	-12.10	Reject H_o**	-1.17
4	"	1.989	-6.78	Reject H_o**	-0.96
1	Phosphate	2.056	1.92	Accept H_o	0.25
2	"	2.024	6.07	Reject H_o**	1.42
3	"	2.026	-1.25	Accept H_o	-0.68
4	"	1.992	87.32	Reject H_o**	68.62
1	Silicate	2.026	2.12	Reject H_o*	0.17
2	"	2.023	0.37	Accept H_o	0.02
3	"	2.024	4.00	Reject H_o**	0.21
4	"	1.987	12.47	Reject H_o**	0.99

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by

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FURTHER STUDIES OF COPPER, ZINC AND CADMIUM IN *MOLPADIA INTERMEDIA* FROM THE POINT GREY DUMPSITE

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1980

Abstract

A second study of the concentrations of copper, zinc and cadmium in the holothurian (sea cucumber) *Molpadia intermedia* is reported. Samples of *M. intermedia* were collected from 19 stations in the Pt. Grey Dumpsite, Georgia Strait and one control station. Copper ranged from 1.9 to 24.0 mg kg^{-1} with a mean of 5.8±5.1(1σ) mg kg^{-1}. Zinc concentrations averaged 139±12 mg kg^{-1} for a range of 118 to 167 mg kg^{-1}. Cadmium was found to have the lowest concentration of the three metals with a range of less than 0.1 to 5.4 mg kg^{-1} and mean of 1.4±1.3 mg kg^{-1}. Data are compared with the first study conducted in 1976. No trends in the station-to-station data from this study were noted for any of the three metals but there was a statistically significant difference for zinc data obtained from the two studies. Data for other elements determined in selected samples by inductively coupled plasma spectrography are reported. The insuitability of *M. intermedia* as biological indicator of ocean dumping impact is discussed in light of the data.

Acknowledgement

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Introduction

In a previous report (Thompson and Paton, 1978a) we described initial efforts to determine concentrations of five heavy metals in the holothurian (sea cucumber), *Molpadia intermedia*. Benthic surveys in March 1976 had shown that this organism was the only one with sufficient ubiquity in the study area. Even in the case of this organism the availability was scant in areas chosen for control purposes.

The metallic elements copper, zinc, cadmium, lead and chromium were determined in samples of the ectoderm and longitudinal muscle which were obtained from specimens obtained from only the northeast quadrant (Hoos, 1977) of the Pt. Grey Dumpsite in Georgia Strait. Because of this limited sampling and the questionable precision for some of the data (particularly for lead, chromium and cadmium) it was considered of some importance that a second, more thorough sampling of the entire dumpsite be made. The primary purposes of this excercise were to determine if:

1. This organism had any use as a biological indicator of heavy metal contamination at the dumpsite.
2. There was any statistically important variation in metal loadings in this organism with location relative to the central area of the dumpsite.

In the follow-up study, reported here, a series of stations from all quadrants of the dumpsite was chosen. Because of the large number of samples involved and financial limitations, data for copper, zinc and cadmium only were obtained.

Our previous report (Thompson and Paton, 1978a) should be consulted for a brief description of the dumpsite.

Materials and Methods

a) Sampling

In July, 1977 at least five specimens of *Molpadia intermedia* were obtained from all stations shown in Figure 1 except at Stations 7, 13, 15, 29 and 36. Samples of bottom sediments were collected in a Smith-MacIntyre grab (Kahl Scientific) and were sieved through a 1 mm mesh polyethylene screen. Specimens collected on the screen were rigorously cleaned of adhering sediment and washed with deionised water. Longitudinal muscle was separated immediately from the ectodermis in a laminar flow HEPA work station. Muscle samples were placed in individual acid-washed glass vials and deep-frozen. Upon return to the laboratory the samples were freeze-dried in their vials and pulverized. Seventy-six specimen samples and six NBS certified Standard samples (4 Orchard Leaves; 2 Bovine Liver) were randomly coded (Table I) and supplied to the contractor for analysis.

b) Analysis

Samples were weighed accurately and transferred to test tubes. Aqua regia (0.5 mL) was added and the samples were digested for one h on a hot water bath. Concentrated nitric acid (10 drops) was added and the samples were heated for another hour. A further half-hour of heating followed addition of 5 drops of 30% hydrogen peroxide. Samples were cooled and diluted to 10.0 mL for subsequent analysis by atomic absorption spectrophotometry.

Analysis was performed with Perkin-Elmer Model 603 (flame aspiration) or Model 306 (heated graphite analyser) atomic absorption spectrophotometers.

i Zinc

Zinc was determined by direct aspiration and flame atomisation with background correction. Reagent blanks were less than 0.01 mg L^{-1}.

ii Copper

Copper above 0.02 mg L^{-1} was determined by direct aspiration and flame atomisation with background correction. Below 0.02 mg L^{-1} determinations were

made by graphite analyser. Reagent blanks were less than 0.001 mg L^{-1}.

iii Cadmium

Cadmium above 0.02 mg L^{-1} was determined by flame atomic absorption with background correction. Below 0.02 mg L^{-1} the graphite analyser was utilised. Reagent blanks were less than 0.001 mg L^{-1}.

Final concentrations of the elements were reported in mg kg^{-1} (dry weight).

For comparison five submitted samples chosen at random and five NBS Certified Standards were analysed using a Jarrell-Ash Model 975 Inductively Coupled Argon Plasma Spectrograph.

Results and Discussion

Analytical data for the 17 dumpsite stations and one control station (F) off the Sechelt Peninsula are presented in Table 1.

a) Copper

Values for copper throughout the 17 dumpsite stations ranged from 1.9 mg kg^{-1} (dry weight) to 24.0 mg kg^{-1}. The overall mean was 5.8±5.1 (1σ). Of more significance are the means on a station-to-station basis which ranged from 3.8 mg kg^{-1} (Station 5) to 0.1 mg kg^{-1} (Station 40). Considering the large standard deviations there is no possibility of there being any significant difference between means for various areas in the dumpsite; nor are there any obvious trends in the copper data. Insufficient control data do not permit any valid comparison with *M. intermedia* from other locales, however it can be noted that copper data for Control F were similar to those for the dumpsite organisms.

Comparison of values for copper from the 1976 sampling (Thompson and Paton, 1978a) with these results shows that the mean copper concentrations in the latter are about one fifth as great. The reason for this is not easily explainable. Analytical procedures were identical and the use of NBS Standards shows that recoveries are within the acceptable limits. It is possible that there was a real decrease in copper content but the probability of a decrease of this magnitude occurring in a period of about 1½ yr is very slight.

Another possibility, though also remote, is that the NE quadrant, studied previously, (Thompson and Paton, 1978a) is richer in copper and zinc to some extent (see below) compared to the other quadrants. The NE sector is nearest the influence of waters from Howe Sound, (see Fig. 1), a source of copper and zinc (Thompson and McComas, 1974; Thompson and Paton, 1976, 1978b) Burrard Inlet (surrounded by metropolitan Vancouver) and the north arm of the Fraser River. Surveys done by the Environmental Protection Service (Hoos, 1977) indicated that sediments in this quadrant contained higher amounts of copper than sediments in the other sector. We do not have sufficient data from this present study to indicate whether or not copper levels in *M. intermedia* from this quadrant are as high as found previously. Stations 9, 25, 27 are the only ones sampled in both studies. Here mean copper concentrations in *M. intermedia* were 4.8, 4.3 and 7.2 mg kg^{-1} respectively against 20, 40 and 23 mg kg^{-1} in the 1976 study. These data would suggest that some other factor (possibly an operational one) has contributed to this considerable change.

b) Zinc

The range of values (Table 1) for zinc for all dumpsite stations was 118-167 mg kg^{-1}. The grand mean and the mean of station means were 139±12 and 137±8 mg kg^{-1} respectively. The greater precision here of about only 8% compared to about 80% for copper reflects the more easily measured quantities of the former. Here, also, there are no trends for data from station to station. The mean value of 128 mg kg^{-1} for the control station is equivalent to or greater than means for three stations within the study area.

Similar to copper, zinc exhibited a decrease of 32 mg kg^{-1} mean value from that from the previous study (Thompson and Paton, 1978a). There was also a notable decrease of from 32% to 8% in the relative standard deviation which may reflect better analytical methods or sampling control or a combination of these. A statistical treatment of these two data sets (Student's 't') indicated that they were significantly different at $P < 0.05$. Comparison of values for zinc at the three stations common to both surveys demonstrated a similar disparity. It might be concluded that better analytical quality control was responsible for these decreases.

c) Cadmium

Values for cadmium shown in Table 1 are close to those reported previously. (Thompson and Paton, 1978a). They range from less than 0.1 to 5.4 mg kg^{-1} The mean of 1.4±1.3 mg kg^{-1} agrees well with a value of 1.7±1.4 in the 1976 study. Here there appears to be some trend in concentrations, with the higher means appearing within and to the west of the immediate dumpsite. A mean of 1.9 mg kg^{-1} for the control samples, however, is well above the inter-station mean of 1.3 mg kg^{-1}, and negates the probability of site-specific influences in the dumpsite given the very large deviations of the mean.

In the previous report (Thompson and Paton, 1978a) it was shown, by provision of standards as dummy samples, that some data were of questionable use. There had been very poor agreement between data for lead in NBS bovine liver submitted to the contractor by us and data from the contractor's bovine liver samples. In this present study, data for submitted standards (NBS Bovine Liver and Orchard Leaves) agreed very well with certified values (Table 2) and as well with values obtained for contractor samples. These results would indicate that the analytical method used provided both accurate and precise measurements.

Useful comparisons were provided by utilizing data obtained from the inductively coupled plasma (ICP) spectrograph. Five samples were chosen at random by the contractor and were analysed for several elements. Table 3 presents data for twelve of these elements including the three being investigated in this work. By coincidence three of the five samples chosen were from station 34. Data obtained allowed some intra-station comparisons to be made.

Copper, zinc and cadmium values from atomic absorption and ICP sources agreed (Table 3) very closely with the largest deviation being only 11 mg kg^{-1} for zinc in sample 34(3). This good agreement again illustrates the degree of dependability of the analytical procedures used.

As can be seen, the data for nine other elements shown in Table 3 exhibit some degree of variability, especially in the cases of calcium and iron and to a lesser extent, silicon. Taken individually, high values for iron and

calcium in samples 4(5) and 34(4) would suggest possible contamination from sediment particles. However, except for higher levels of silicon and strontium in sample 4(5), other data, notably those for copper and zinc are not concomittantly higher as might be expected if sediments were the source.

The arsenic values are of interest as they demonstrate that *M. intermedia*, like a number of other invertebrates, possess a strong tendency to concentrate this element. Vertebrate fishes normally contain arsenic at the low mg kg^{-1} level.

The intent of this and the preliminary study (Thompson and Paton, 1978a) was to determine: 1. The usefulness of the holothurian, *Molpadia intermedia*, as a suitable monitor species for heavy metal contamination and 2. Whether or not the use of the dumpsite in Georgia Strait off Pt. Grey for several years had resulted in heavy metal contamination.

We were thwarted in our efforts at the outset of sampling because it became apparent that there was a paucity of suitable control sites. We had used Control Station F in the first sampling and were confident that suitable numbers for comparison with animals from the dumpsite would be obtained. Besides various sites in Georgia Strait we also made an extensive search in the Satellite Channel area north of the Saanich Peninsula, having had previous information regarding their availability there.

Although a sometimes inordinate number of casts of the sampler were required we were able to obtain sufficient quantities of *M. intermedia* at most stations in the dumpsite area. The relatively large population of this species and another holothurian, (*Chiridota* sp.), in the dumpsite area had been noted previously by Hoos (1977). The abundance of benthic infauna in general was notable throughout the entire area. Whether this was due to an improved habitat provided by dumped material or a normal situation cannot be determined. Some influence from the nearby Fraser River might be a contributing factor also.

Thus, because of the lack of control samples a valid statistical analysis of comparative copper, zinc and cadmium concentrations cannot be made. The

considerable natural variability of copper and cadmium in *M. intermedia* would, furthermore, prevent comparison, even with suitable controls unless a very sizable uptake of these elements occurred.

A third factor which would be of some importance in any possible utilization of *M. intermedia* would be sample size since the major part of the organism consists of sediment-filled digestive tract. The allowance for depuration period is used commonly when bivalves such as the mussels are collected for contaminant studies. Application of this technique to *M. intermedia* however would not appear feasible as a means of inducing the animal to discharge gut contents.

The data reported here and in our previous study (Thompson and Paton, 1978a) are probably the first published for trace elements in organisms of this class (*Holothuroidea*). Because of this it is not possible to make comparisons with data from other locations. There are some data available for classes in the same phylum (*Echinodermata*). Riley and Segar (1970) report data for eighteen elements in starfish (*Asteroidea*), and urchins (*Echinoidea*) which are epibenthic feeders. Copper, zinc, cadmium, manganese and calcium values reported are similar to those given here. Iron was highly variable as was the case with *M. intermedia*. There have been some unsubstantiated claims that holothurians are noteworthy collectors of iron; however there are not concrete literature data to support these claims, nor do our data give them support.

Finally, if the problem is considered in terms of the need for a suitable organism for use as an indicator of contamination from dumped wastes it is suggested that *M. intermedia* does not meet requirements. An alternate approach, possibly using some long-term bioassay procedures or another as yet unidentified benthic organism might be considered if the need for such an indicator is still considered necessary.

Conclusions

The metals copper, zinc and cadmium have been determined in the holothurian *Molpadia intermedia* obtained from nineteen stations in the area

of the Pt. Grey dumpsite and one control station. Analytical results indicate that there are no trends in the station-to-station distribution of any of the three elements studied. A statistically significant ($P < 0.05$) decrease in zinc concentrations between these results and those reported previously (Thompson and Paton, 1978a) was observed. A similar, but not significant decrease for copper was also noted. Reasons other than analytical can be suggested but not identified.

The organism is not suitable as a monitoring species because of wide natural variability, small sample sizes and lack of sufficient control specimens.

Literature Cited

Hoos, R.A.W. 1977. Environmental assessment of an ocean dumpsite in the Strait of Georgia, B.C. Environmental Protection Service Report No. EPS 5-PR-77-2. 31 pp.

Riley, J.P. and D.A. Segar. 1970. The distribution of the major and some minor elements in marine animals. I. Echinoderms and coelenterates. J. Mar. Biol. Ass., U.K. 50: 721-730.

Thompson, J.A.J. and F.T. McComas. 1974. Copper and zinc levels in submerged mine tailings at Britannia Beach, B.C. Fish. Res. Bd. Can. Tech. Rept. No. 473, 33 pp.

Thompson, J.A.J. and D.W. Paton. 1976. Further studies of mine tailings distribution in Howe Sound, B.C. Fish. Res. Bd. Can. Manuscript Rept. Ser. No. 1383, 14 pp.

______________________. 1978a. Heavy metals in benthic organism from Pt. Grey Dumpsite - Vancouver, B.C. A preliminary report. Unpublished Manuscript. Pacific Marine Science Report 78-11. 18 pp.

______________________. 1978b. Copper in sediment interstitial waters and overlying waters of Howe Sound, B.C. Fish. Mar. Ser. Tech. Rept. No. 775, 29 pp.

Table 1

Heavy Metal Concentrations in Muscle Tissue of *Molpadia intermedia*

Station (sample #)	Code No.		Cu $mg.kg^{-1}$	Zn $mg.kg^{-1}$	Cd $mg.kg^{-1}$
F(1)[a]	69		4.6	112	1.2
(2)	57		8.0	132	1.4
(3)	47		15.5	124	3.7
(4)	25		2.3	145	0.7
(5)	10		2.9	130	2.7
		$\bar{x}$	6.6	129	1.9
		σ	±5.4	±12.0	±1.2
1(1)	66		5.7	145	0.7
(2)	55		15.6	126	<0.5
(3)	44		1.9	131	0.3
(4)	33		7.0	145	<0.3
(5)	22		2.7	137	0.6 (n=3)
		$\bar{x}$	6.6	137	0.5
		σ	±5.5	± 8.4	±1.2
2(1)	73		14.7	154	1.6
(2)	38		2.3	148	0.8
(3)	19		2.3	130	0.5
(4)	4		2.8	153	1.5
		$\bar{x}$	5.5	146	1.1
		σ	±6.1	±11	±0.5
4(1)	15		1.9	138	0.5
(2)	28		4.1	161	0.3
(3)	48		4.0	150	0.9
(4)	59		24.0	137	1.2
(5)	74		4.4	121	4.3
		$\bar{x}$	7.8	141	1.4
		σ	±9.2	±15	±1.6
5(1)	67		5.7	145	0.7
(2)	18		2.3	130	0.5
(3)	30		2.1	154	0.5
(4)	68		4.0	134	0.3
(5)	39		5.3	145	<1.3
		$\bar{x}$	3.9	142	0.5 (n=4)
		σ	±1.7	±10	0.2

Table 1 con't

Station (sample #)	Code No.		Cu $mg.kg^{-1}$	Zn $mg.kg^{-1}$	Cd $mg.kg^{-1}$
7(1)	78		20.2	118	0.5
(2)	16		4.5	128	0.4
(3)	51		2.0	141	<0.7
		$\bar{x}$	8.9	129	0.5 (n=2)
		σ	±1.0	±12	±0.1
9(1)	6		1.9	144	0.7
(2)	17		2.9	124	0.7
(3)	40		6.3	132	0.2
(4)	53		3.9	132	1.0
(5)	65		9.2	148	2.4
		$\bar{x}$	4.8	136	1.0
		σ	±2.9	±10	±0.8
11(1)	3		5.3	142	1.7
(2)	76		3.6	145	0.4
(3)	32		2.8	134	0.2
(4)	58		6.6	154	5.0
(5)	21		4.3	127	<0.1
		$\bar{x}$	4.5	141	1.8 (n=4)
		σ	±1.5	±10	±2.2
13(1)	54		3.7	124	<0.2
(2)	5		17.6	142	1.0
(3)	70		2.0	121	0.2
(4)	37		1.5	139	1.0
		$\bar{x}$	6.2	132	0.7 (n=3)
		σ	±7.7	±11	±0.5
15(1)	23		2.7	142	0.7
(2)	49		6.9	132	3.8
(3)	62		14.2	136	5.4
		$\bar{x}$	7.9	138	3.3
		σ	±5.8	± 5	±2.4
25(1)	11		3.4	148	1.3
(2)	35		5.3	133	1.1
(3)	50		8.2	143	<0.4
(4)	61		2.2	136	0.3
(5)	72		2.4	167	0.3
		$\bar{x}$	4.3	145	0.8 (n=4)
		σ	±2.5	±13	±0.5

Table 1 con't

Station (sample #)	Code No.		Cu $mg.kg^{-1}$	Zn $mg.kg^{-1}$	Cd $mg.kg^{-1}$
27(1)	77		23.3	144	3.1
(2)	9		2.3	141	<0.4
(3)	45		4.2	120	0.4
(4)	71		2.9	131	<0.1
(5)	36		3.5	143	0.6
		$\bar{x}$	7.2	136	1.4
		σ	±9.0	±10	±1.5
29(1)	26		2.9	127	0.5
(2)	42		5.6	150	0.6
(3)	60		3.8	140	0.2
(4)	79		2.0	145	0.8
		$\bar{x}$	3.6	141	0.5
		σ	±1.5	±10	±0.3
31(1)	46		7.7	121	<1.1
34(1)	25		3.8	154	1.6
(2)	7		3.5	125	1.2
(3)	56		5.1	147	1.5
(4)	13		6.6	139	3.5
(5)	34		1.9	150	0.2
		$\bar{x}$	4.2	143	1.6
		σ	±1.8	±12	±1.2
36(1)	1		3.0	128	1.2
(2)	14		8.6	120	2.9
		$\bar{x}$	5.8	124	2.1
		σ	–	–	–
38(1)	12		4.5	127	5.2
(2)	24		5.0	139	1.1
(3)	63		5.1	147	0.6
(4)	41		2.9	160	0.5
(5)	31		5.6	163	<0.6
		$\bar{x}$	4.6	147	1.9 (n=4)
		σ	±1.0	±15	±2.3
40(1)	2		14.9	132	2.1
(2)	8		2.9	134	2.9
(3)	20		6.5	152	1.2
(4)	29		4.7	152	2.3
(5)	43		16.6	137	0.4

Table 1 con't

Station (sample #)	Code No.	Cu mg.kg^{-1}	Zn mg.kg^{-1}	Cd mg.kg^{-1}
	$\bar{x}$	9.1	141	1.8
	σ	±6.2	±10	±1.0
	Mean for all samples	5.8 ± 5.1	139 ± 12	1.4 ± 1.3
	Mean of Station means	5.9 ± 1.8	137 ± 8	1.3 ± 0.7

[a] Control Station - Georgia Str. off Sechelt Penninsula (49° 21.6'N, 123° 34.8'W)

Table 2

Metal Concentrations in NBS Certified Standards
(Submitted with *M. intermedia* Samples)

	Sample #	Code #	Cu $mg.kg^{-1}$	Zn $mg.kg^{-1}$	Cd $mg.kg^{-1}$
Orchard Leaves (SRM 1571)	1	27	10.9	23	0.1
	2	52	11.2	23	0.1
	3	64	11.6	24	0.1
	4	81	11.9	26	0.1
		$\bar{x}$	11.4	24.0	0.1
		σ	±0.44	±1.4	0
	Certified Value		12 ± 1	25 ± 3	0.11 ± 0.01
Bovine Liver (SRM 1577)	1	80	193	131	0.3
	2	82	189	131	0.3
		$\bar{x}$	191	131	0.3
	Certified Value		193 ± 10	130 ± 10	0.27 ± 0.04

Table 3

Plasma Spectograph Data for Selected Samples[a]

Station (sample #)	Code #	Cu(b)	Zn(b)	Cd(b)	As	Ca	Co	Fe	Mn	Si	Sr	Ti	V
4(5)	74	4.7(4.4)	121(121)	3.8(4.3)	72	3.9×10^3	N.D.[c]	2.4×10^4	80	1.0×10^3	209	2.0	4
5(2)	18	2.5(2.3)	132(130)	<2(0.5)	80	$1.6\ 10^3$	9	390	26	270	32	2	2
34(3)	56	4.9(5.1)	136(147)	<2(1.5)	71	1.6×10^3	6	270	63	270	31	1	1
34(4)	13	7.5(6.6)	145(139)	4.0(3.5)	177	2.8×10^3	30	4.1×10^3	54	350	80	10	10
34(5)	34	2.1(1.9)	153(150)	<2.5(0.2)	31	1.7×10^3	6	270	30	290	30	4	5

a mg.kg^{-1} dry weight

b AA data from Table I for comparison in parentheses

c not determined

Caption to Figure 1

Location of Pt. Grey dumpsite and stations occupied in present study. Numbers correspond to those determined by EPS (Hoos, 1977).

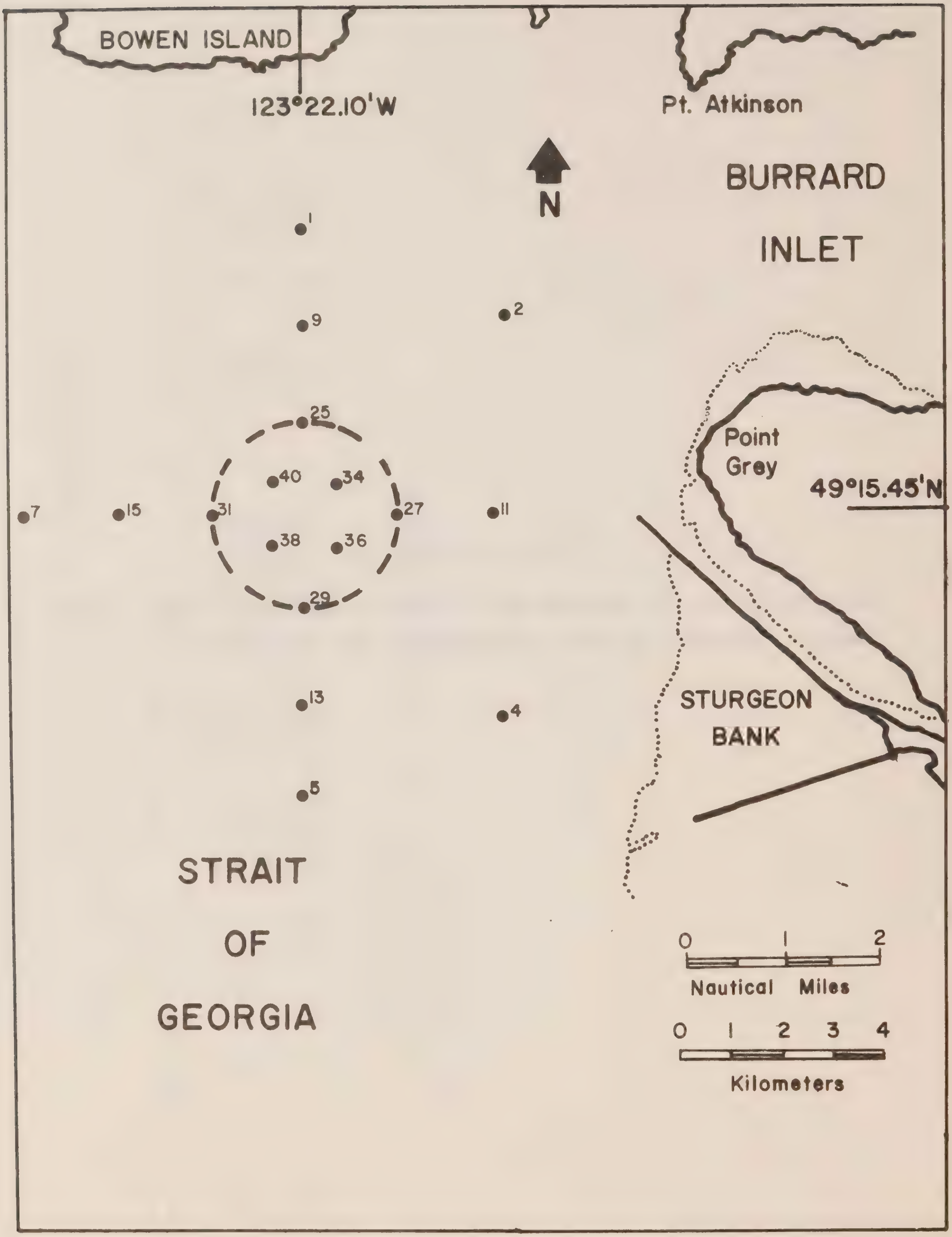
BOWEN ISLAND
123°22.10'W
Pt. Atkinson
N
BURRARD
INLET
1
9
2
25
40
34
7
15
31
27
11
38
36
29
Point
Grey
49°15.45'N
13
4
5
STURGEON
BANK
STRAIT
OF
GEORGIA
0 1 2
Nautical Miles
0 1 2 3 4
Kilometers

Figure 1

Pacific Marine Science Report 80-4

LORAN-C AND OMEGA NAVIGATION SYSTEM TESTS IN THE BEAUFORT SEA

by

A. Mortimer and P. Milner

INSTITUTE OF OCEAN SCIENCES
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Sidney, B.C. CANADA
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1980

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10.	" "	- Narrow Cape (7960-X)	"
11.	" "	- Shoal Cove (7960-X)	"
12.	" "	- St. Paul I. (9990-Master)	"
13.	" "	- Port Clarence (9990-Y)	"
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Abstract

This report describes Loran-C skywave reception in the Beaufort Sea. The accuracy of Loran-C positions using this mode of reception is evaluated. Omega reception was also monitored in the Beaufort Sea and the accuracy of positions obtained with an MX1105 Satnav/Omega receiver are given.

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Magnavox Corporation, Torrance, California

Marinav Corporation, Ottawa, Ontario

Introduction

The Beaufort Sea extends northward from the Canadian and Alaskan coasts into the Arctic Ocean west of Longitude 128°W. It is an area of intensive petroleum resource exploration activity and there is a possibility that oil tanker traffic will develop in the next few years. The continental shelf extends up to 75 nautical miles (nm) out from the low-lying coastline. The shelf is liberally scattered with shoal pingo-like features which rise to within 16 metres (m) of the surface. These shoals, together with the poor radar targets presented by the low-lying coast, present problems for the navigator who already has to cope with the usual hazards of arctic navigation.

Several navigation systems and techniques are available in the Beaufort Sea. This area is, of course, covered by the U.S. Navy Satellite Navigation system (Satnav) and by Omega. There is a potential for limited Loran-C reception using skywaves from the existing chains in Alaska. Seven radar beacons operate from positions along the shore, providing targets with radar ranges of up to 25 nm. Several air radio direction finder beacons exist in the area, and V.L.F. (Very low frequency) transmissions may be available from several stations in the northern hemisphere. The oil exploration companies use a number of precise inshore positioning systems such as Argo and Syledis. The Polar Continental Shelf Project (PCSP) of the Department of Energy, Mines and Resources intermittently operates a Decca 6F chain providing coverage of portions of the Beaufort Sea. So for offshore navigation, there already exist three potentially useful systems covering all of the Beaufort Sea: (1) Satnav, (2) Omega, (3) Loran-C.

Satnav provides accurate fixes on the average every 50 minutes at these latitudes. However gaps between passes may be as long as three hours, either due to the geometry of the current satellite orbital configuration or to interference occurring when two satellites are above the horizon. The Satnav system has been successfully used in this area since 1970 and continues to be used for precise drill ship positioning, survey work and general navigation. However unless Satnav position information is integrated with data from some other system it does not provide continuous positioning information.

Omega is one of the radio navigation systems that provide continuous coverage in the area. Phase comparisons are made using V.L.F. signals (10.2, 11.3 and 13.6 Khz). This system, unless used in conjunction with Satnav or with local monitor, does not provide the accuracy that is usually required for navigation on the continental shelf. Omega reception is also subject to diurnal propagation changes, sudden ionospheric disturbances, polar cap disturbances and from inadequately modelled propagation path conductivity variations. Signals from four of the eight Omega stations can be regularly received in the Beaufort Sea area. The stations are Norway (A), Hawaii (C), North Dakota (D) and Japan (H). It is interesting to note that the V.L.F. propagation path from Norway to the Beaufort Sea does not pass over the Greenland icecap. Therefore this particular signal is not as strongly attenuated as it is in the eastern Canadian Arctic.

LORAN C COVERAGE IN THE NORTH EAST PACIFIC

CANADA

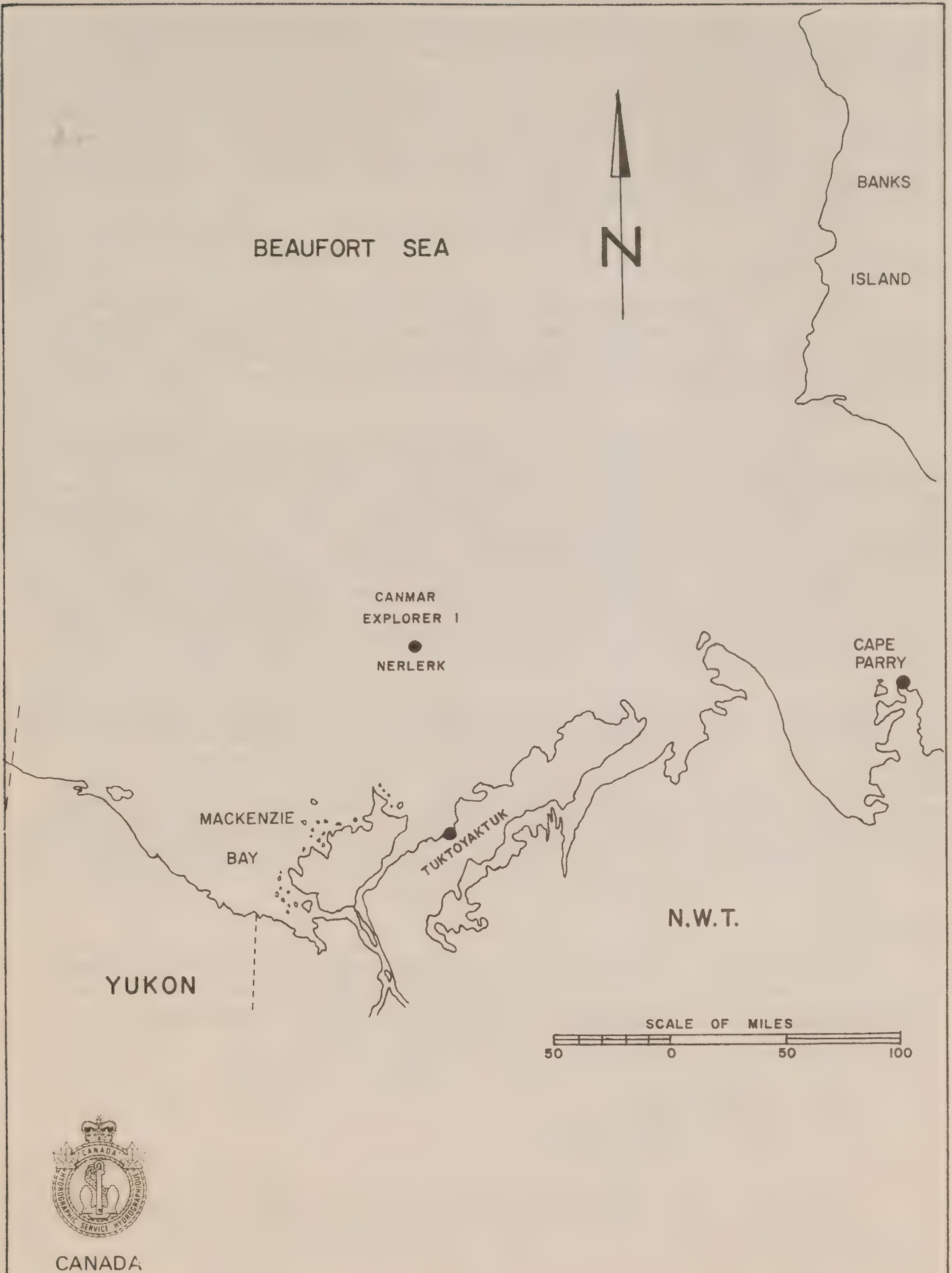

BEAUFORT SEA
N
BANKS
ISLAND
CANMAR
EXPLORER I
NERLERK
CAPE
PARRY
MACKENZIE
BAY
TUKTOYAKTUK
N.W.T.
YUKON
SCALE OF MILES
50
0
50
100
CANADA
HYDROGRAPHIC SERVICE HYDROGRAPHIQUE
CANADA

Figure 2

Two Loran-C chains operate in Alaska, and are designed to provide groundwave coverage of the Gulf of Alaska and the Bering Sea. However, Loran-C has a predicted one-hop skywave range of about 1300 nm. Therefore, transmissions from five stations in Alaska can usually be received. One of the signals, from Tok (7690 M) can be reliably received on groundwave, at least during the summer. The other stations providing skywave coverage are Narrow Cape (7960-X, 9990-Z), Shoal Cove (7960-Y), St. Paul Is. (9990-M) and Port Clarence (9990-Y). (See Figure 1.)

Purpose of Tests

Reports of reasonably reliable Loran-C reception were received from ship operators in the Beaufort Sea in 1977 and 1978. In response to these reports a series of tests was made in August, 1979. In addition to the Loran-C measurements the opportunity was taken to investigate Omega reception in the area.

The Loran-C tests were made to show the availability and stability of signals from the Alaska transmitters at three sites in the Beaufort Sea area, (1) at Tuktoyaktuk, (2) at the Nerlerk M-98 drill site in CANMAR *Explorer 1* and (3) at Cape Parry. (See Figure 2.) The tests were designed to establish the extent of Loran-C groundwave reception, the reliability and stability of Loran-C skywave reception, and the accuracy of time difference (T.D.) and time of arrival (T.O.A.) position lines. Data were collected to define the signal to noise ratio (S.N.R.), the envelope to cycle difference, the receiver gain (which can be related to field strength), the T.O.A. and T.D. of Loran-C signals.

Omega data were collected at Tuktoyaktuk and in CANMAR *Explorer 1*. For this navigation system signal to noise and position information were measured at both sites. An attempt was also made to estimate the effect of differential corrections to Omega positions. However, the permanent Omega monitor at Inuvik was not operational when the measurements were being made in the Beaufort Sea. Some data from this monitor were made available by the United States Coast Guard for a short period after our observations were made.

Equipment

To monitor the Loran-C signals in the Beaufort Sea an Austron Loran-C receiver system was used. The system was controlled by a monitor program similar to that used for operational chain monitoring. The system was made up of the following equipment:

1 Austron 5000 Monitor Receiver
1 D.E.C. PDP8E Computer
1 T.I. A.S.R. 733 Data Terminal
1 H.P. 5062-C Cesium Frequency Standard.

Loran-C T.D., phase, gain, cycle and noise information was logged on Phillips cassettes and later transcribed to Hewlett Packard cartridges for data processing.

To monitor the Omega signals Magnavox 1105 Satellite/Omega Navigator was used. This instrument was lent to the CHS by the Magnavox Government and Industrial Electronics Company of Torrance, California, through Marinav Ltd. of Ottawa, Ontario. The MX1105 combines information from a single channel (400 mhz) satellite navigation system receiver with data from a three frequency Omega receiver through a Z80 microprocessor. This system produces satellite positions, Omega positions and signal/noise and position line bias information, also integrated position estimates from both navigation sensors. Provision is also made for ship's log and gyro input, although this feature was not used in the tests. The MX1105 designates the integrated positions - Nav. 1 for the Satnav/Log/Gyro combination and Nav.2 for the Satnav Omega combination.

Measurements at Tuktoyaktuk

Loran-C signals were monitored at Tuktoyaktuk, in CANMAR *Explorer 1* and at Cape Parry. At Tuktoyaktuk, the Loran-C equipment was set up at the Polar Continental Shelf Project (PCSP) base. The antenna, a 2.5 m whip, was placed on the roof of the building about 10 m above the ground and about 15 m above sea level, well clear of all obstructions. Monitoring started at 1500 local time (2200Z) on August 4th, 1979. The transmissions for the Gulf of Alaska Chain (7960) from Tok (Master) and from Narrow Cape (X-Secondary) were quickly acquired. The transmissions for Bering Sea Chain (9990) from Port Clarence (Y-Secondary) and again from Narrow Cape (Z-Secondary) were also easily acquired. At about 0100 local time, just after sunset, the signals from Shoal Cove (7960, Y-Secondary) and from St. Paul Is. (9990, Master) were acquired. The signals from these five stations were tracked continuously for 72 hours with only occasional cycle skips on the transmissions from Shoal Cove, Narrow Cape and St. Paul Is. A data set, defining T.O.A., T.D., Gain, Noise and Cycle, was logged every 15 minutes.

Some interference to Loran-C reception was observed at Tuktoyaktuk. This interference was observed on the scope of the Austron 5000 receiver as a transmission somewhere close to 100 Khz formed into a continuous pulse train, the pulse envelope having a wavelength approximately ten times that of the basic frequency. This continuous pulse train swept across the scope with an apparent repetition interval of 85,000 microseconds. The pulses reached their maximum amplitude during the afternoon, then decreased to a minimum at night.

A spectrum analyser showed a reasonably clean spectrum around 100 Khz, with the Loran-C signals easily identifiable above the noise, at about -100 dbm. However, the analyser did show a pulsed transmission sweeping this area of the spectrum. The Tuktoyaktuk DEW line station chief reports interference on some of their equipment at 121.5 Khz.

The Omega and Satnav antennae for the MX1105 system were also placed on the roof of the PCSP base at Tuktoyaktuk about 3 m away from the Loran-C antenna and from each other. It took this system about 6 hrs to acquire and synchronise with the Omega transmissions of Tuktoyaktuk. Data relating to Omega and integrated positions, and Omega signal quality were logged every

30 minutes for 72 hours. For the next 48 hrs the MX1105 system was used as a stand-alone Omega receiver and Omega position data was again logged every 30 minutes.

Measurements at Nerlerk in *Explorer 1*

Radio navigation signals were monitored in CANMAR *Explorer 1*, a drill ship working about 60 nm north of Tuktoyaktuk in the Beaufort Sea. The ship was, for our purposes, stationary on the drill site. The Loran-C antenna was mounted on the bridge wing about 15 m above sea level. The Omega and Satnav antenna were placed on the flying bridge about 20 m above sea level. The drill rig tower was about 30 m northwest of the antenna and obviously such a massive structure would not enhance low frequency phase measurements. Also the drill ship provided a "noisy" environment for monitoring radio signals. However, no major distortions in accuracy of position data collected in CANMAR *Explorer 1* could be attributed to either the rig or the "noise".

In the drill ship, Loran-C signals from Tok (7960-Master), Narrow Cape (7980 - X-Secondary, 9990 - Z-Secondary) and Port Clarence (9990 - Y-Secondary) were quickly acquired under daytime conditions. The transmission from Shoal Cove (7960 - Y-Secondary) was acquired at sunset. It was not possible to acquire the signal from St. Paul Is. (9990 - Master) until the second night in the ship. Transmissions from these five stations were monitored for 72 hrs. Considering the noisy environment, receiver tracking ability appeared acceptable as only about two cycle skips per day were experienced for each station; except Tok which was completely stable.

Difficulty was experienced in acquiring the Omega signals onboard the drill ship. The MX1105 was operated for 24 hrs before synchronization with the Omega transmissions was established. Once synchronization had occurred, strong signals were received from five Omega transmitters (A, C, D, G, H) for the following 24 hrs. At this time, the MX1105 was put into the Omega stand-alone mode. However, the system lost the Omega signals at about 0200 local time (middle of the night). Upon re-synchronization only three Omega stations (C, D, G) were tracked and they were erratic. Good position data was not obtained again until well after sunrise from either the integrated or stand-alone Omega systems.

Measurements at Cape Parry

Only Loran-C transmissions were monitored at Cape Parry, which is 180 nm east of Tuktoyaktuk. The Loran-C monitoring equipment was set up at the DEW line site and the whip antenna was mounted on the roof of the building about 100 m above sea level and 80 m from the radar dome. Signals from four Loran-C stations were monitored for 48 hrs. Stations at Tok (7960 - Master), Narrow Cape (7960 - X-Secondary; 9990 - Z-Secondary) and Port Clarence (9990 - Y-Secondary) were acquired within 3 hrs of setting up during the afternoon. Shoal Cove (7960 - Y-Secondary) could not be acquired until sunset. It was not possible to acquire the signal from St. Paul Is. (9990 - Master) during this 48 hr period. Radio interference throughout

the monitoring period at Cape Parry was minimal. An attempt was made to track skywave from Tok (7960 - Master) during the night at about 0100 local time. The skywave on this transmission was distinctly separated from the groundwave for only a short period of time, but enough measurements were made to enable the night time ionospheric height to be estimated.

Loran-C Data

Figures 3 through 8 show the information collected at Tuktoyaktuk for the two chains monitored. Times of arrival, in microseconds, of the various transmissions are plotted for the three days. All but the signals from Tok (7960 - Master) show the effects of skywave propagation. The cycle number shown on the graphs is related to envelope-to-cycle-difference (E.C.D.):

$$\text{E.C.D.} = (3.0 - \text{Cycle \#}) \times 10.$$

Gain numbers from the Austron Loran-C Monitor system are shown on these figures. They can be related to field strengths for the signals through:

$$F = 50 \times 10^{\frac{110 - \text{Gain \# (db)}}{20}}$$

where F = Field Strength (microvolts per metre).

Data collected at Nerlerk (CANMAR *Explorer 1*) is shown in Figures 9 through to 14. Again all the T.O.A.'s plotted, except those from Tok (7960 - Master) show skywave activity. The measurements made at Cape Parry are graphed in Figures 15 through to 19.

Omega Data

The position data generated by the MX1105 Omega/Satnav system are shown in the figures in Appendix I. In this appendix the latitudes and longitudes for Satnav fixes, for the integrated (Nav. 2) positions and for the Omega fixes are plotted as time series, for each day and as three day blocks.

Scatter plots for the positions given by the MX1105 at Tuktoyaktuk, from Satnav, Omega and integrated (Nav. 2) outputs are shown in Figures 20 to 24. Figures 25, 26 and 27 show the scatter plots of positions from the MX1105's three position outputs at Nerlerk (CANMAR *Explorer 1*).

Loran-C Reception - Groundwave from Tok

The distances from the monitor sites in the Beaufort Sea to the transmitters are given in Table 1.

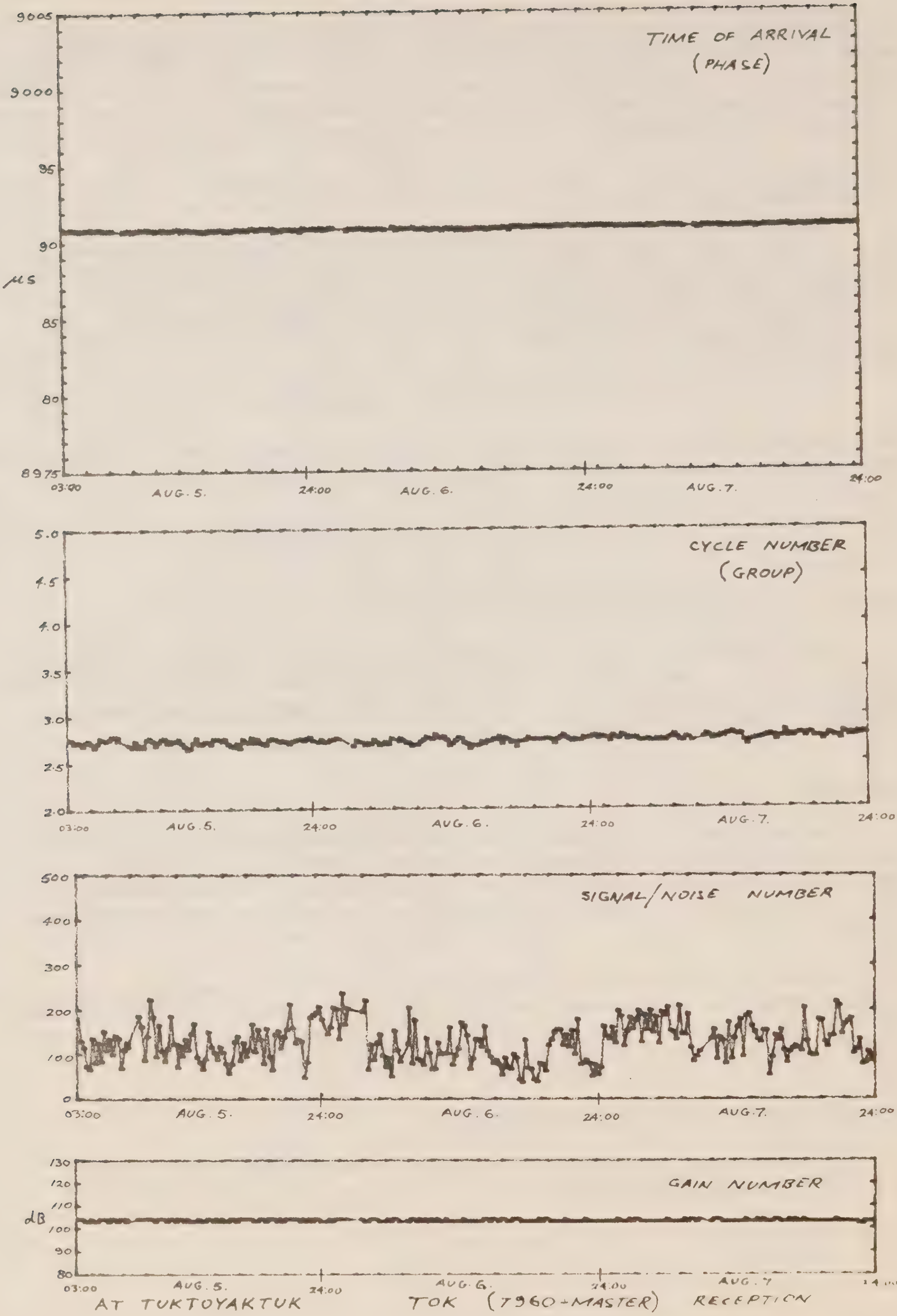

TIME OF ARRIVAL
(PHASE)
9005
9000
95
90
μs
85
80
8975
03:00
AUG. 5.
24:00
AUG. 6.
24:00
AUG. 7.
24:00
CYCLE NUMBER
(GROUP)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
SIGNAL/NOISE NUMBER
500
400
300
200
100
0
GAIN NUMBER
130
120
110
dB
100
90
80
AT TUKTOYAKTUK
TOK (7960-MASTER) RECEPTION

Figure 3

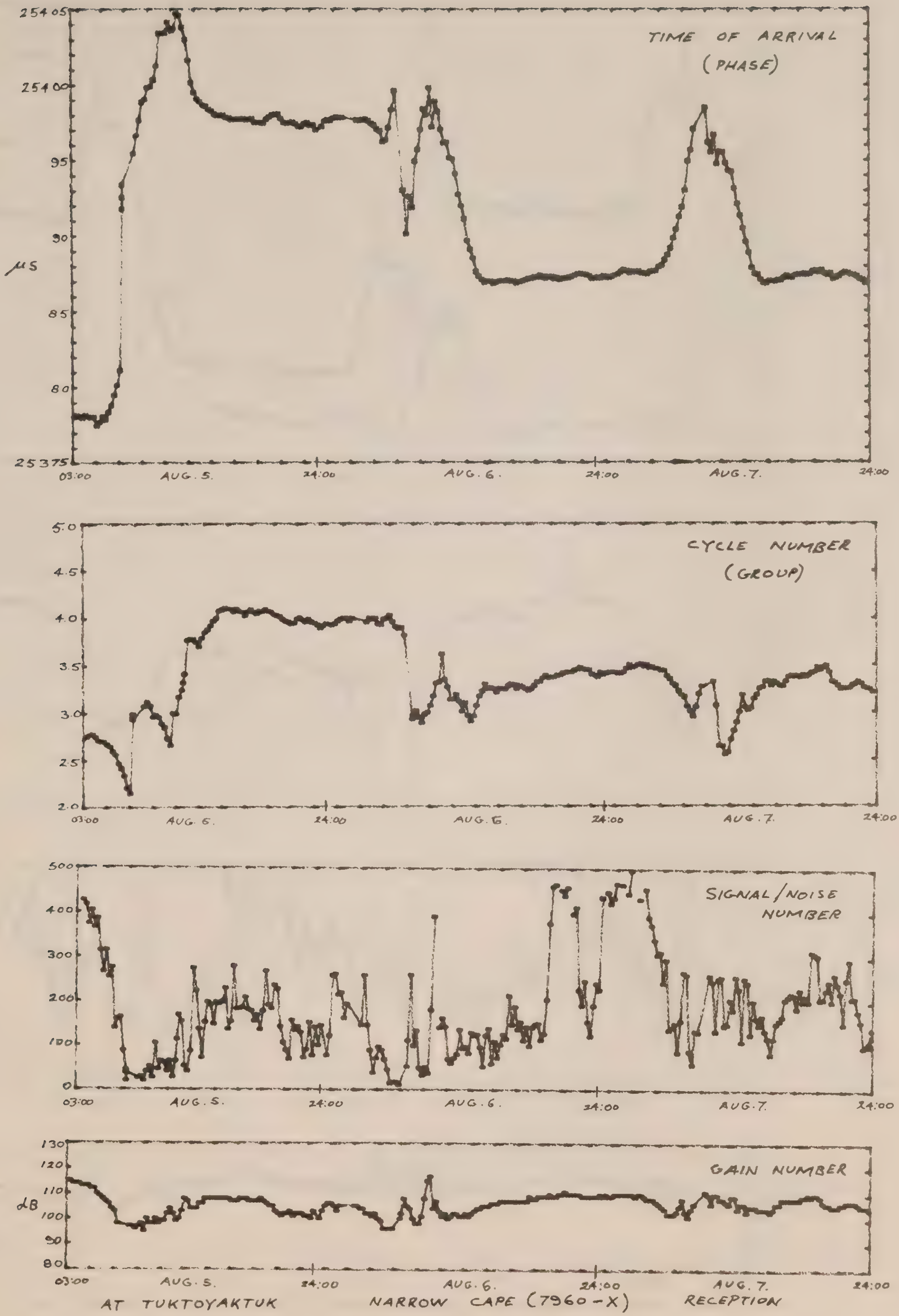
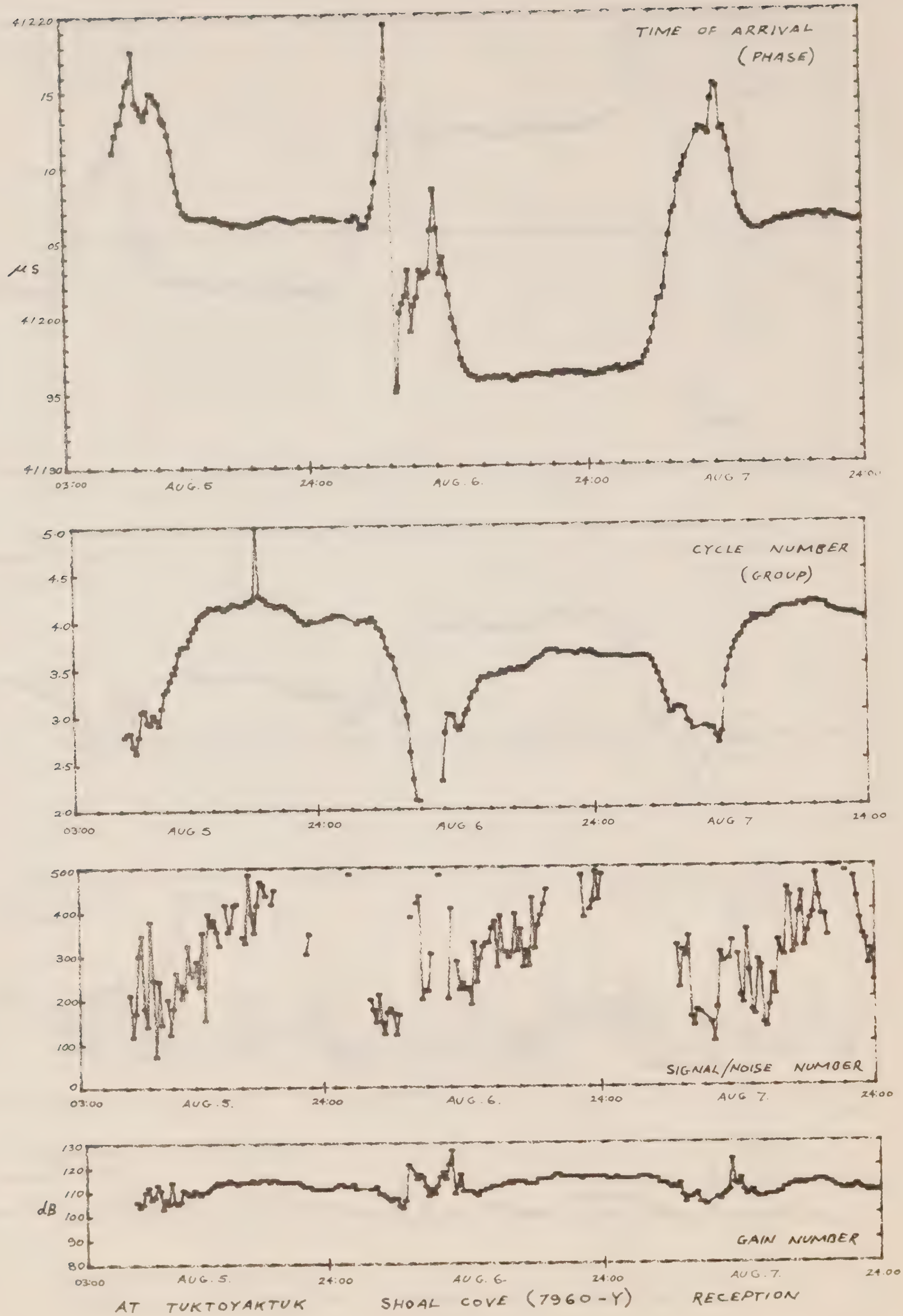

TIME OF ARRIVAL
(PHASE)
25405
25400
95
90
μs
85
80
25375
03:00
AUG. 5.
24:00
AUG. 6.
24:00
AUG. 7.
24:00
CYCLE NUMBER
(GROUP)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
SIGNAL/NOISE
NUMBER
500
400
300
200
100
0
GAIN NUMBER
130
120
110
dB
100
90
80
AT TUKTOYAKTUK NARROW CAPE (7960-X) RECEPTION

Figure 4


TIME OF ARRIVAL
(PHASE)
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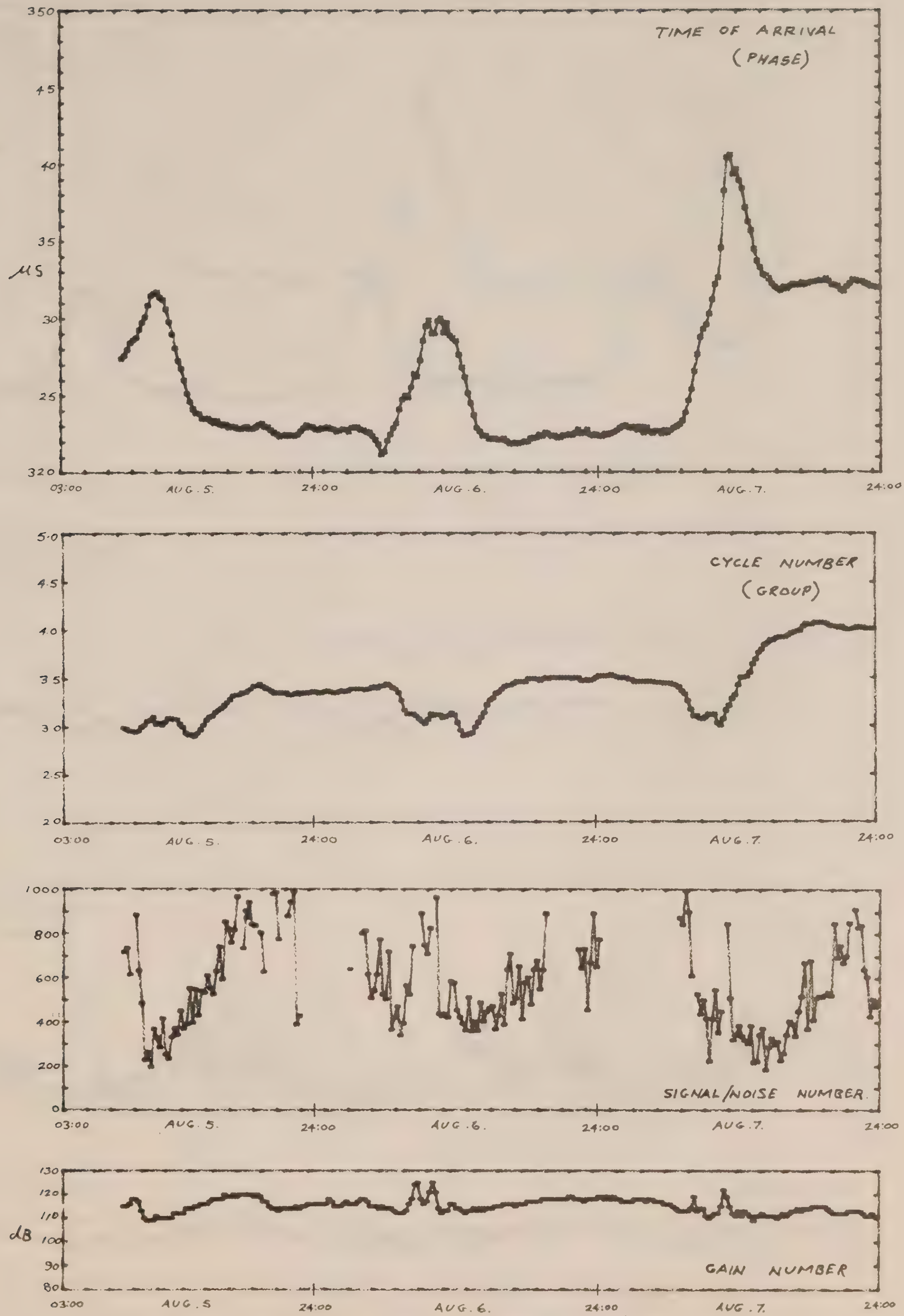
15
10
05
µS
41200
95
41190
03:00
AUG. 5
24:00
AUG. 6
24:00
AUG 7
CYCLE NUMBER
(GROUP)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
SIGNAL/NOISE NUMBER
500
400
300
200
100
0
GAIN NUMBER
130
120
110
dB
100
90
80
AT TUKTOYAKTUK SHOAL COVE (7960-Y) RECEPTION

Figure 5



AT TUKTOYAKTUK ST. PAUL I. (9990-MASTER) RECEPTION

Figure 6

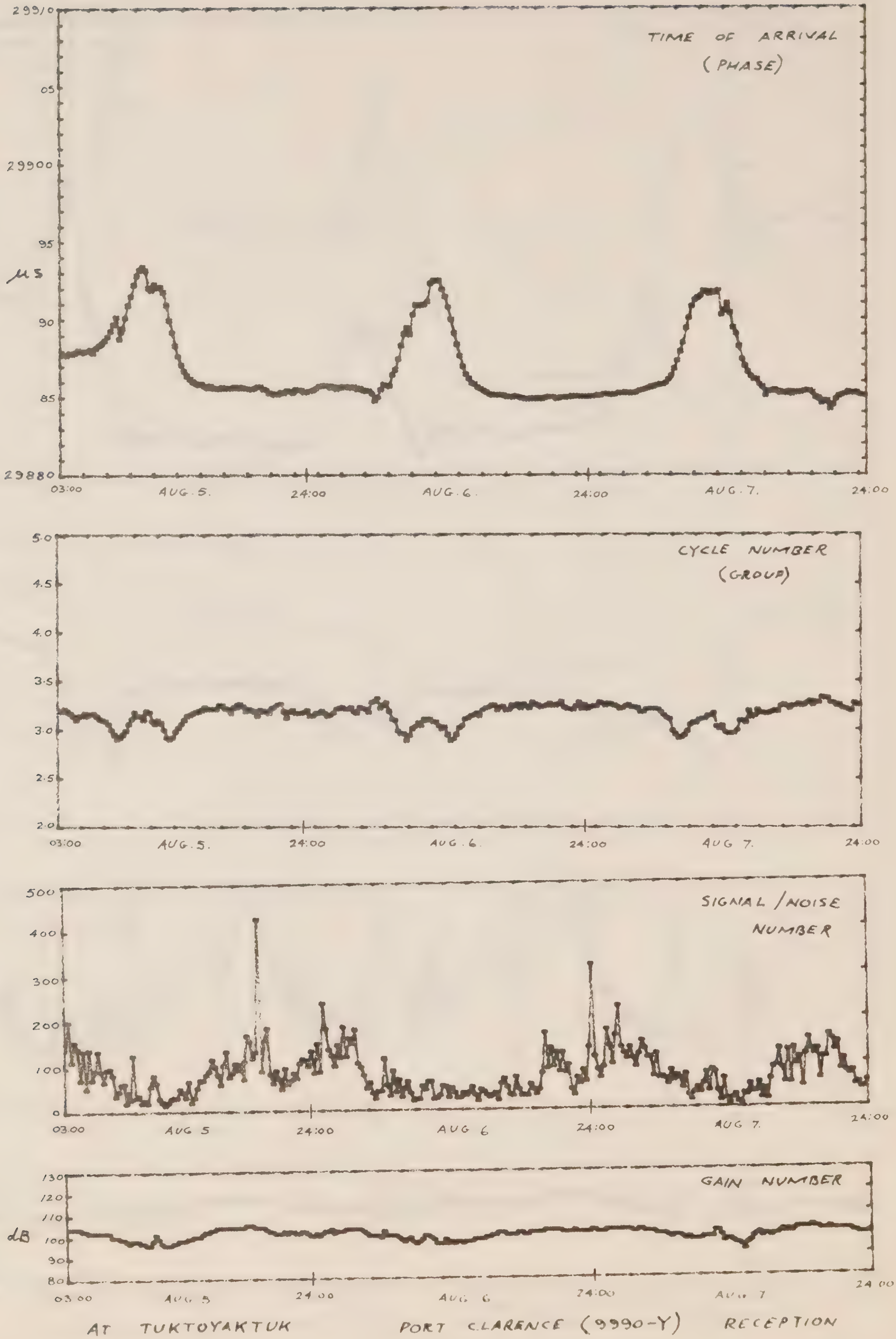

TIME OF ARRIVAL
(PHASE)
μs
29910
05
29900
95
90
85
29880
03:00
AUG.5.
24:00
AUG.6.
24:00
AUG.7.
24:00
CYCLE NUMBER
(GROUP)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
03:00
AUG.5.
24:00
AUG.6.
24:00
AUG 7.
24:00
SIGNAL/NOISE
NUMBER
500
400
300
200
100
0
03:00
AUG 5
24:00
AUG 6
24:00
AUG 7.
24:00
GAIN NUMBER
dB
130
120
110
100
90
80
03.00
AUG 5
24 00
AUG 6
24:00
AUG 7
24 00
AT TUKTOYAKTUK
PORT CLARENCE (9990-Y)
RECEPTION

Figure 7

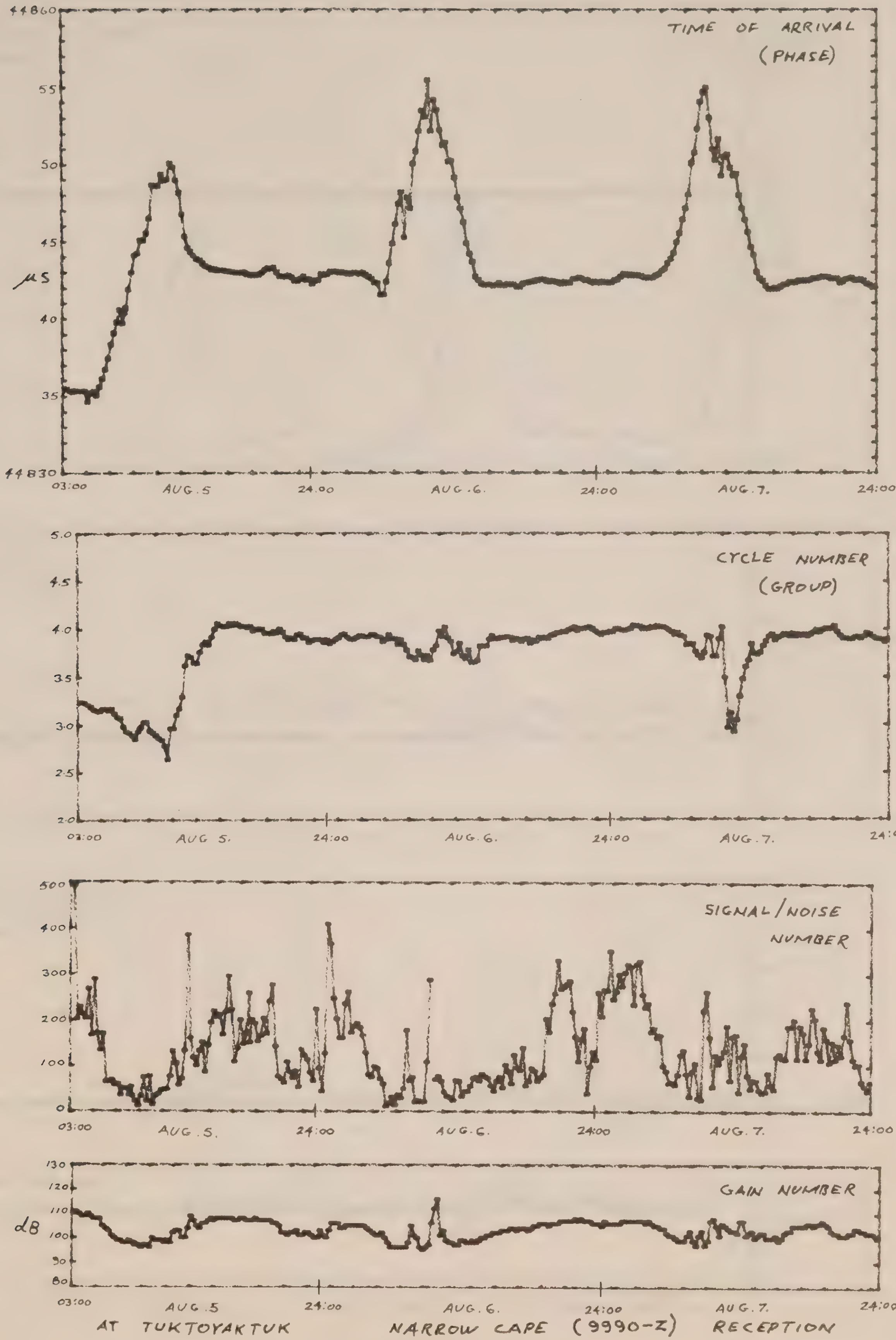

TIME OF ARRIVAL (PHASE)
44860
55
50
45
μS
40
35
44830
03:00
AUG.5
24:00
AUG.6.
24:00
AUG.7.
24:00
CYCLE NUMBER (GROUP)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
03:00
AUG 5.
24:00
AUG.6.
24:00
AUG.7.
24:00
SIGNAL/NOISE NUMBER
500
400
300
200
100
0
03:00
AUG.5.
24:00
AUG.6.
24:00
AUG.7.
24:00
GAIN NUMBER
130
120
110
dB
100
90
80
03:00
AUG.5
24:00
AUG.6.
24:00
AUG.7.
24:00
AT TUKTOYAKTUK NARROW CAPE (9990-Z) RECEPTION

Figure 8

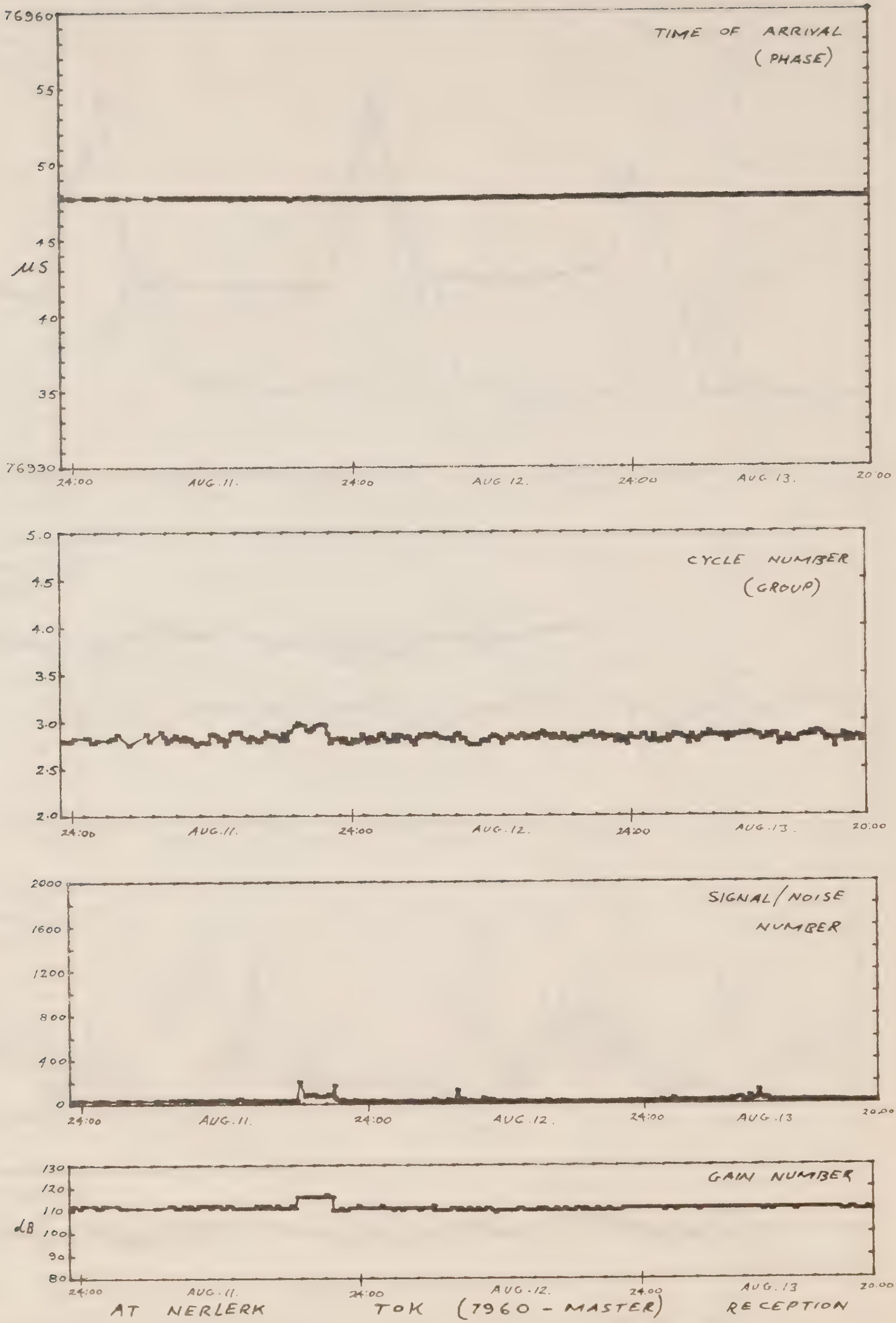

TIME OF ARRIVAL (PHASE)
76960
55
50
45
μS
40
35
76930
24:00
AUG. 11.
24:00
AUG 12.
24:00
AUG 13.
20:00
CYCLE NUMBER (GROUP)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
SIGNAL/NOISE NUMBER
2000
1600
1200
800
400
0
GAIN NUMBER
130
120
110
dB
100
90
80
AT NERLERK TOK (7960 - MASTER) RECEPTION

Figure 9

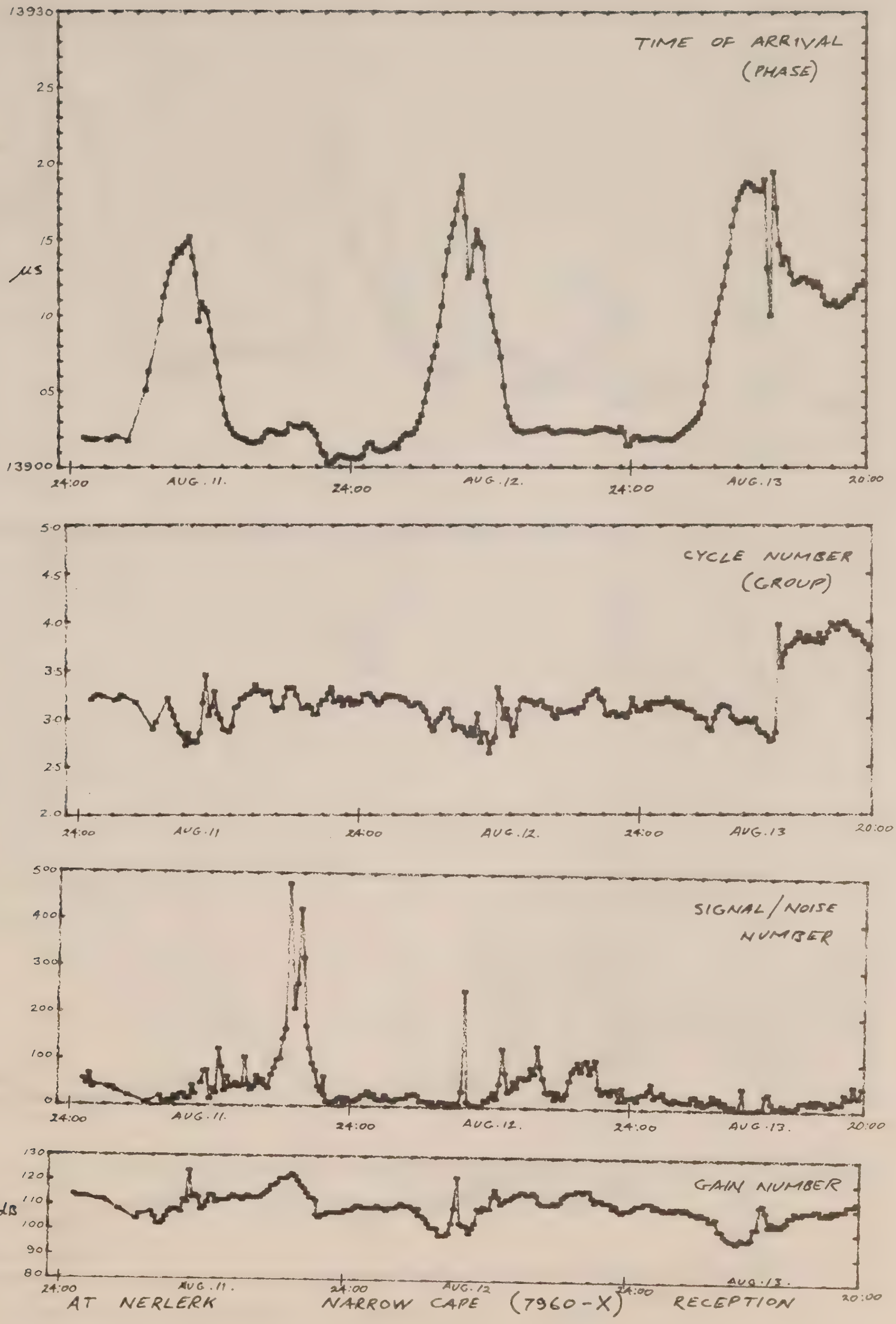

TIME OF ARRIVAL
(PHASE)
13930
25
20
15
μs
10
05
13900
24:00
AUG. 11.
24:00
AUG. 12.
24:00
AUG. 13
20:00
CYCLE NUMBER
(GROUP)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
24:00
AUG. 11
24:00
AUG. 12.
24:00
AUG. 13
20:00
SIGNAL / NOISE
NUMBER
500
400
300
200
100
0
24:00
AUG. 11.
24:00
AUG. 12.
24:00
AUG. 13.
20:00
GAIN NUMBER
130
120
110
dB
100
90
80
24:00
AUG. 11.
24:00
AUG. 12
24:00
AUG. 13.
20:00
AT NERLERK NARROW CAPE (7960-X) RECEPTION

Figure 10

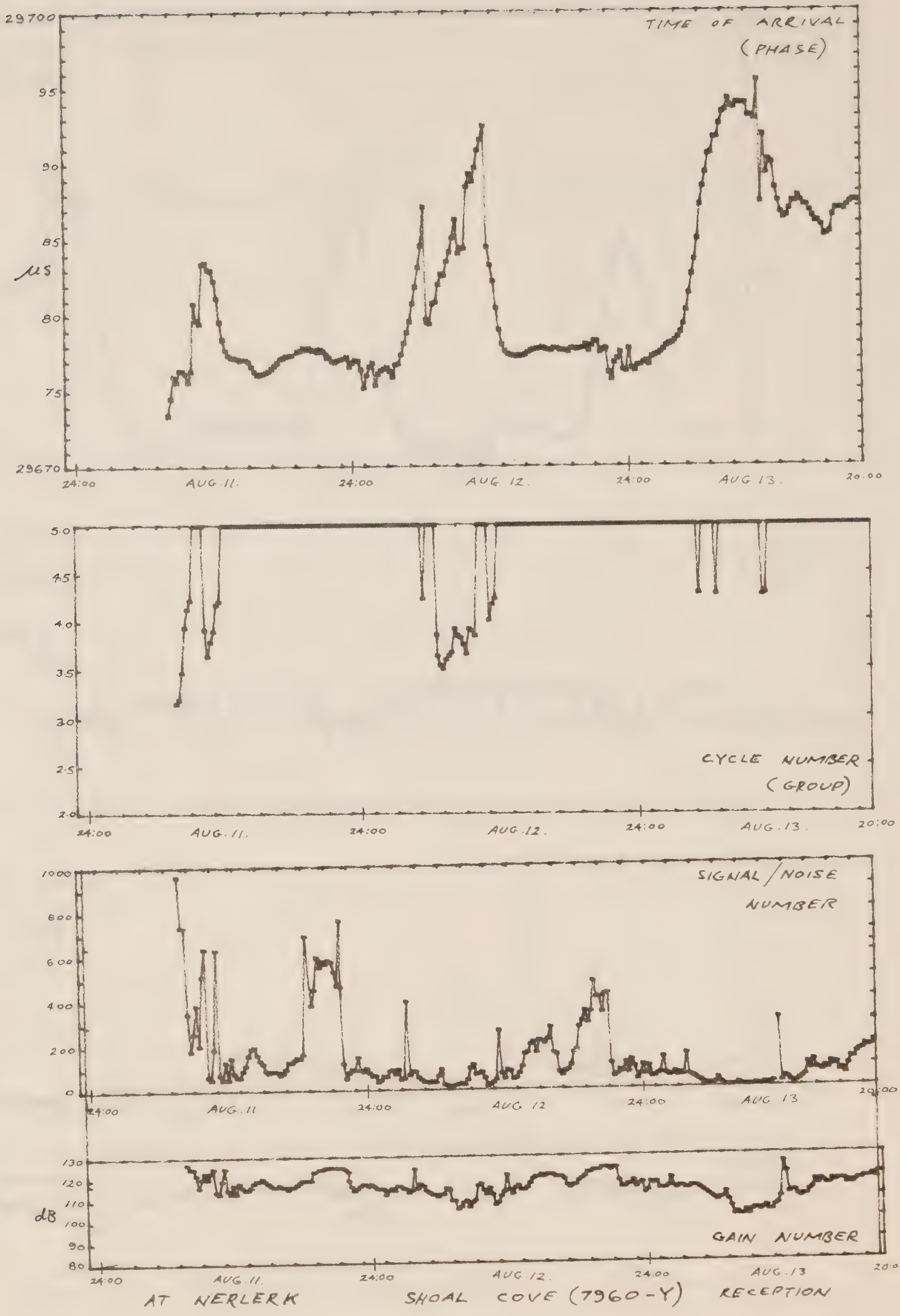

TIME OF ARRIVAL
(PHASE)
29700
95
90
85
μs
80
75
29670
24:00
AUG. 11.
24:00
AUG 12.
24:00
AUG 13.
20:00
5.0
4.5
4.0
3.5
3.0
2.5
2.0
CYCLE NUMBER
(GROUP)
24:00
AUG. 11.
24:00
AUG. 12.
24:00
AUG. 13.
20:00
1000
800
600
400
200
0
SIGNAL / NOISE
NUMBER
24:00
AUG. 11
24:00
AUG 12
24:00
AUG 13
20:00
130
120
110
dB
100
90
80
GAIN NUMBER
24:00
AUG. 11.
24:00
AUG. 12.
24:00
AUG. 13
20:00
AT NERLERK SHOAL COVE (7960-Y) RECEPTION

Figure 11

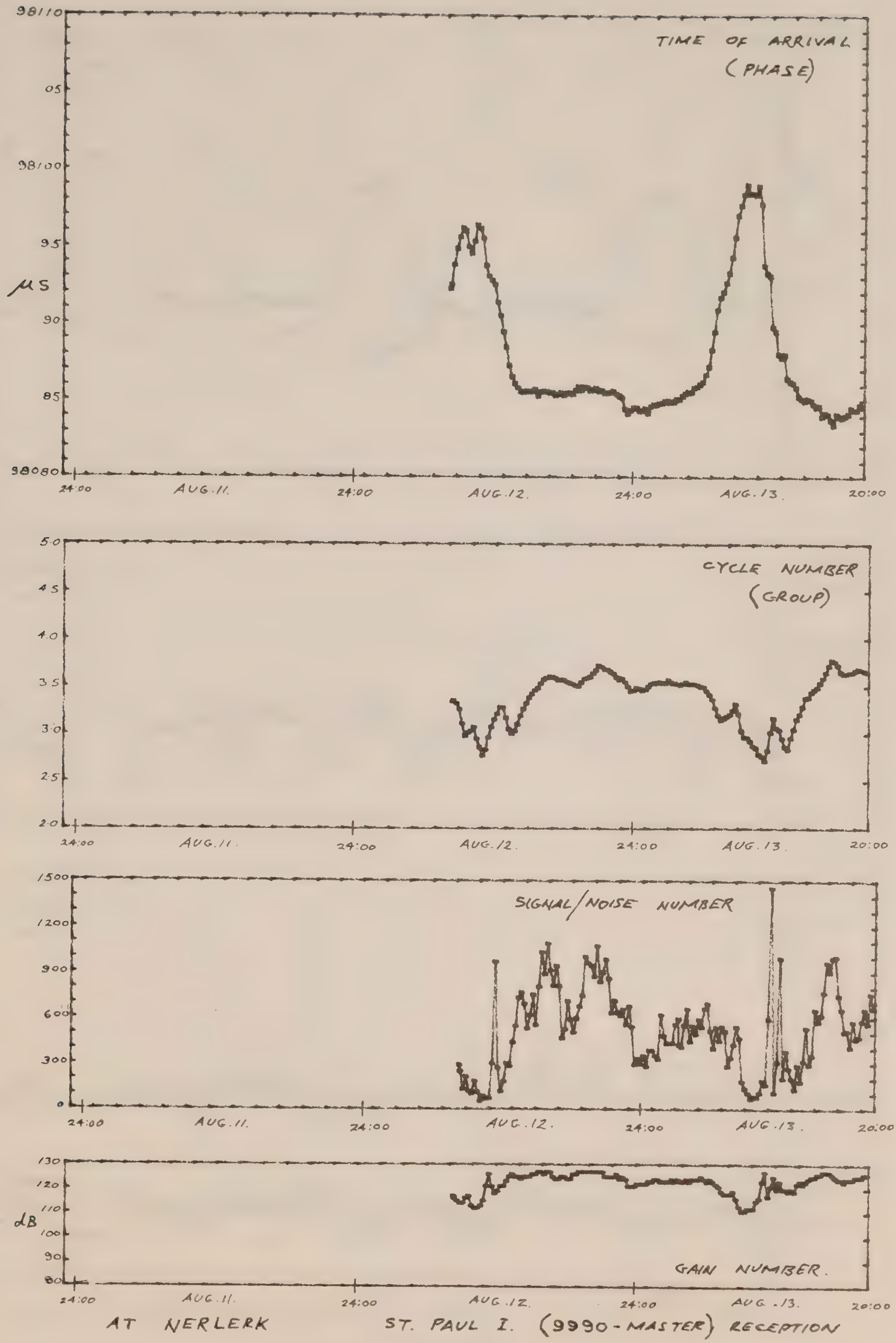
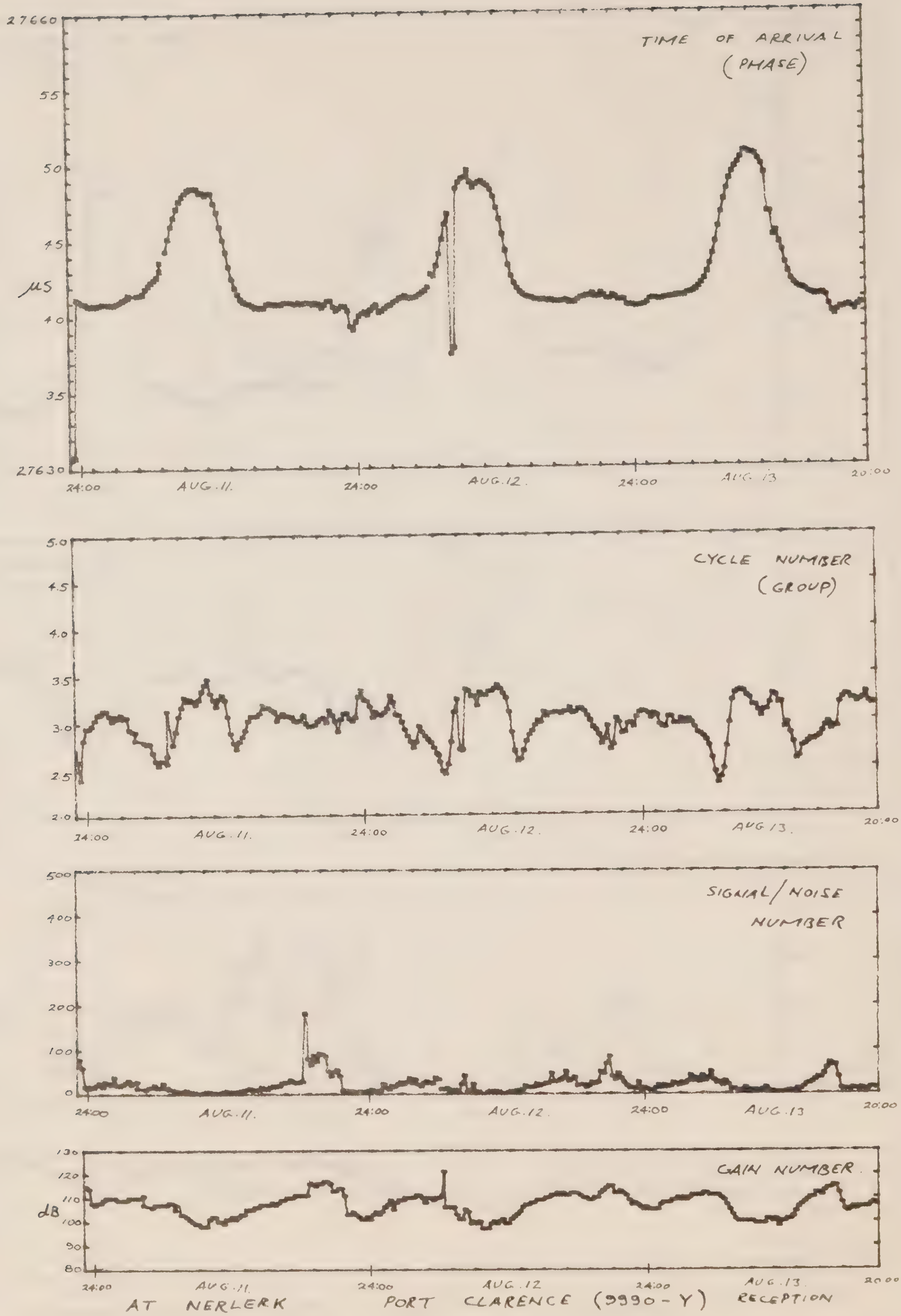
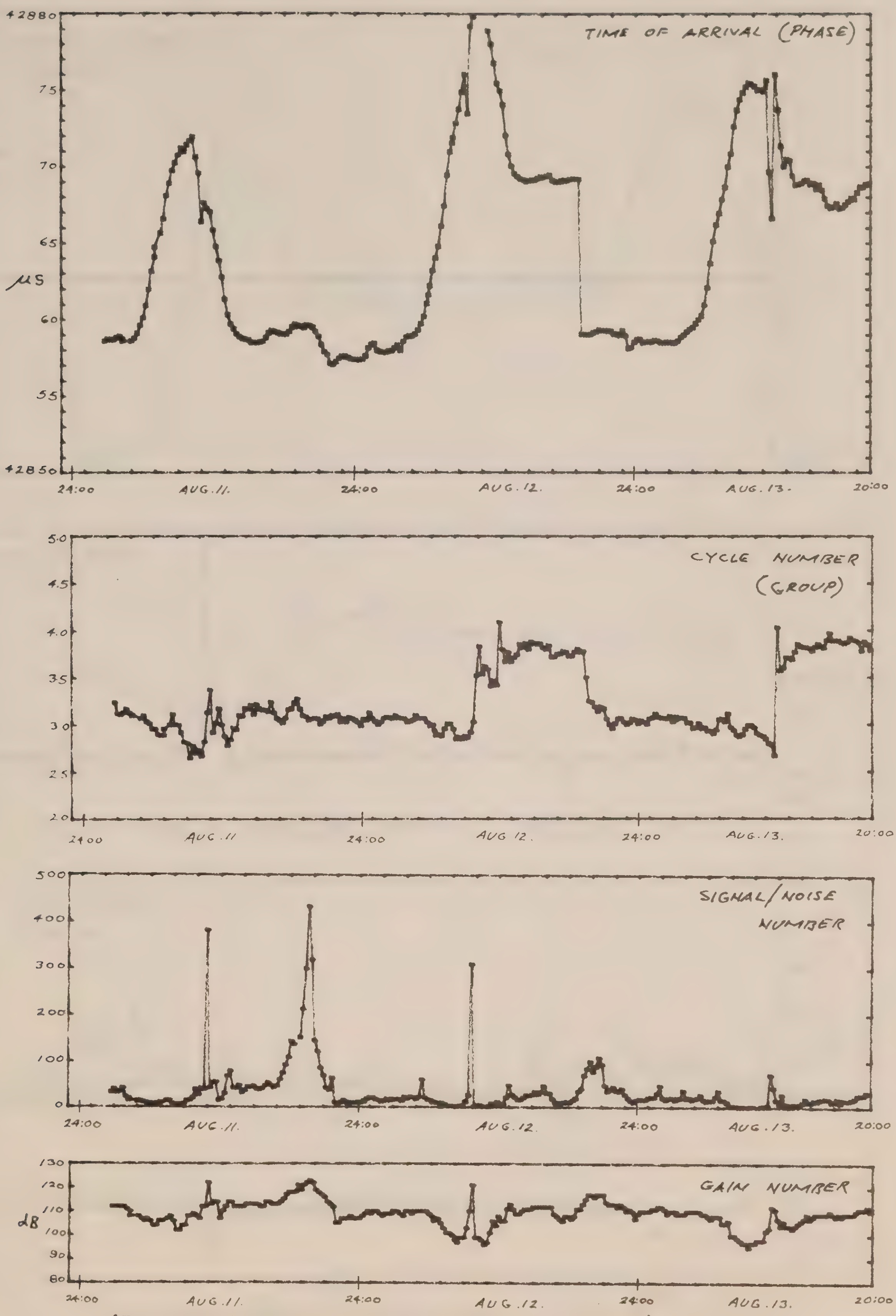

98110
05
98100
95
μS
90
85
98080
TIME OF ARRIVAL
(PHASE)
24:00
AUG.11.
24:00
AUG.12.
24:00
AUG.13.
20:00
5.0
4.5
4.0
3.5
3.0
2.5
2.0
CYCLE NUMBER
(GROUP)
1500
1200
900
600
300
0
SIGNAL/NOISE NUMBER
130
120
110
dB
100
90
80
GAIN NUMBER.
AT NERLERK
ST. PAUL I. (9990-MASTER) RECEPTION

Figure 12



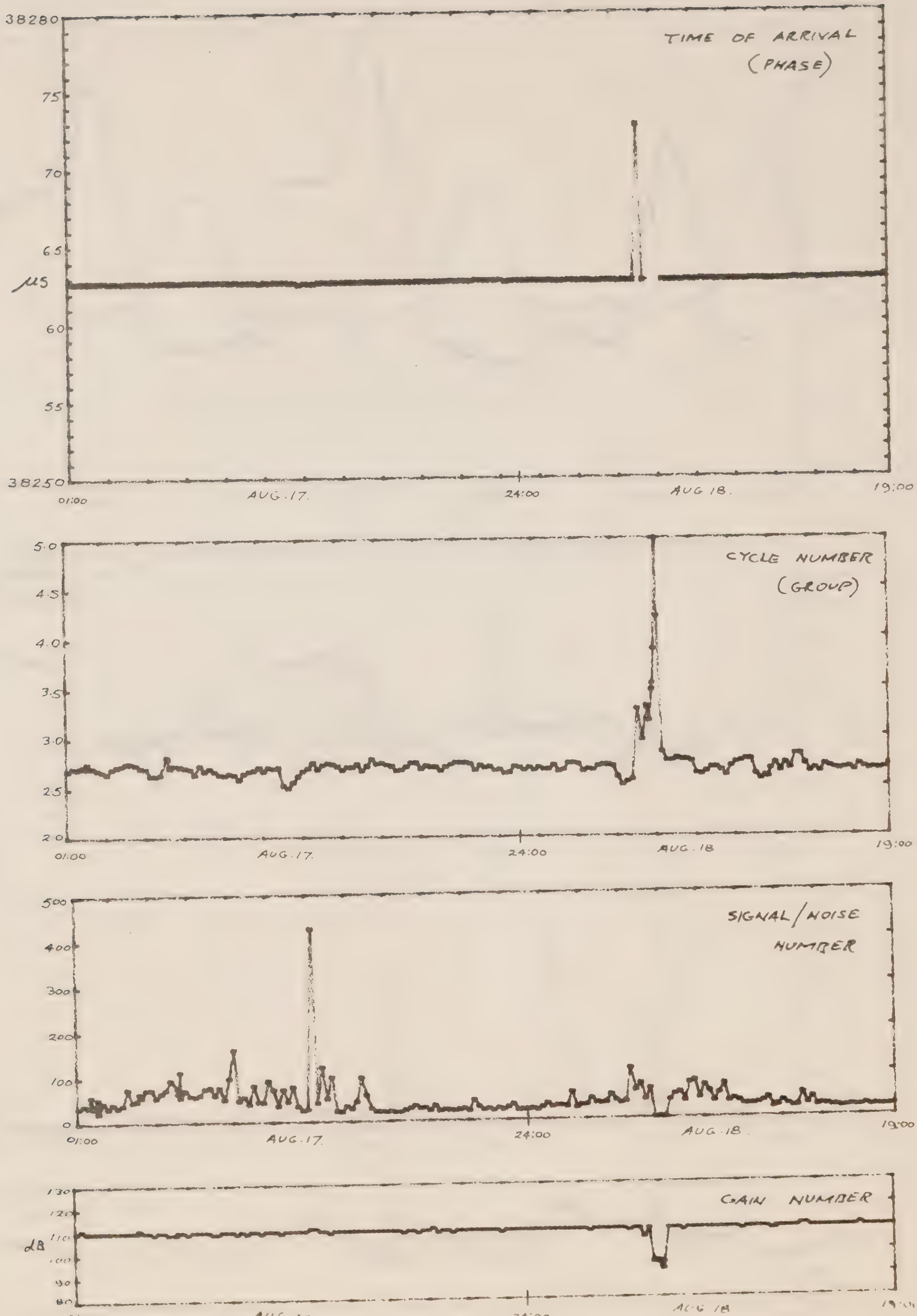
TIME OF ARRIVAL (PHASE)
27660
55
50
45
μS
40
35
27630
24:00
AUG. 11.
24:00
AUG. 12.
24:00
AUG. 13
20:00
CYCLE NUMBER (GROUP)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
SIGNAL/NOISE NUMBER
500
400
300
200
100
0
GAIN NUMBER.
130
120
110
dB
100
90
80
AT NERLERK PORT CLARENCE (9990-Y) RECEPTION

Figure 13



AT NERLERK NARROW CAPE (9990-Z) RECEPTION

Figure 14



AT CAPE PARRY TOK (7960-MASTER) RECEPTION

Figure 15

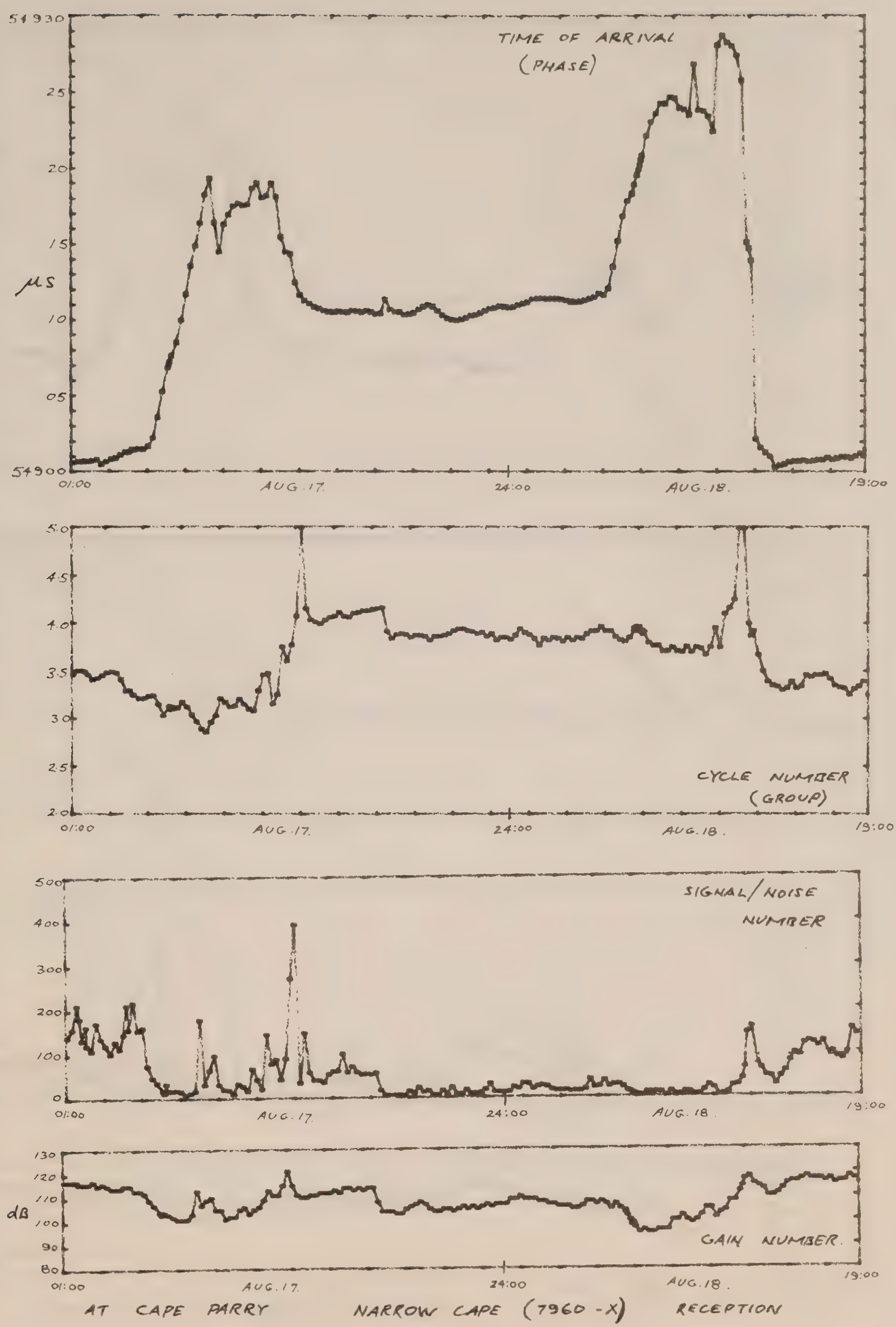

TIME OF ARRIVAL
(PHASE)
54930
25
20
15
μs
10
05
54900
01:00
AUG. 17.
24:00
AUG. 18.
19:00
5.0
4.5
4.0
3.5
3.0
2.5
2.0
CYCLE NUMBER
(GROUP)
01:00
AUG. 17.
24:00
AUG. 18.
19:00
500
400
300
200
100
0
SIGNAL/NOISE
NUMBER
01:00
AUG. 17.
24:00
AUG. 18
19:00
130
120
110
dB
100
90
80
GAIN NUMBER.
01:00
AUG. 17.
24:00
AUG. 18.
19:00
AT CAPE PARRY NARROW CAPE (7960 - X) RECEPTION

Figure 16

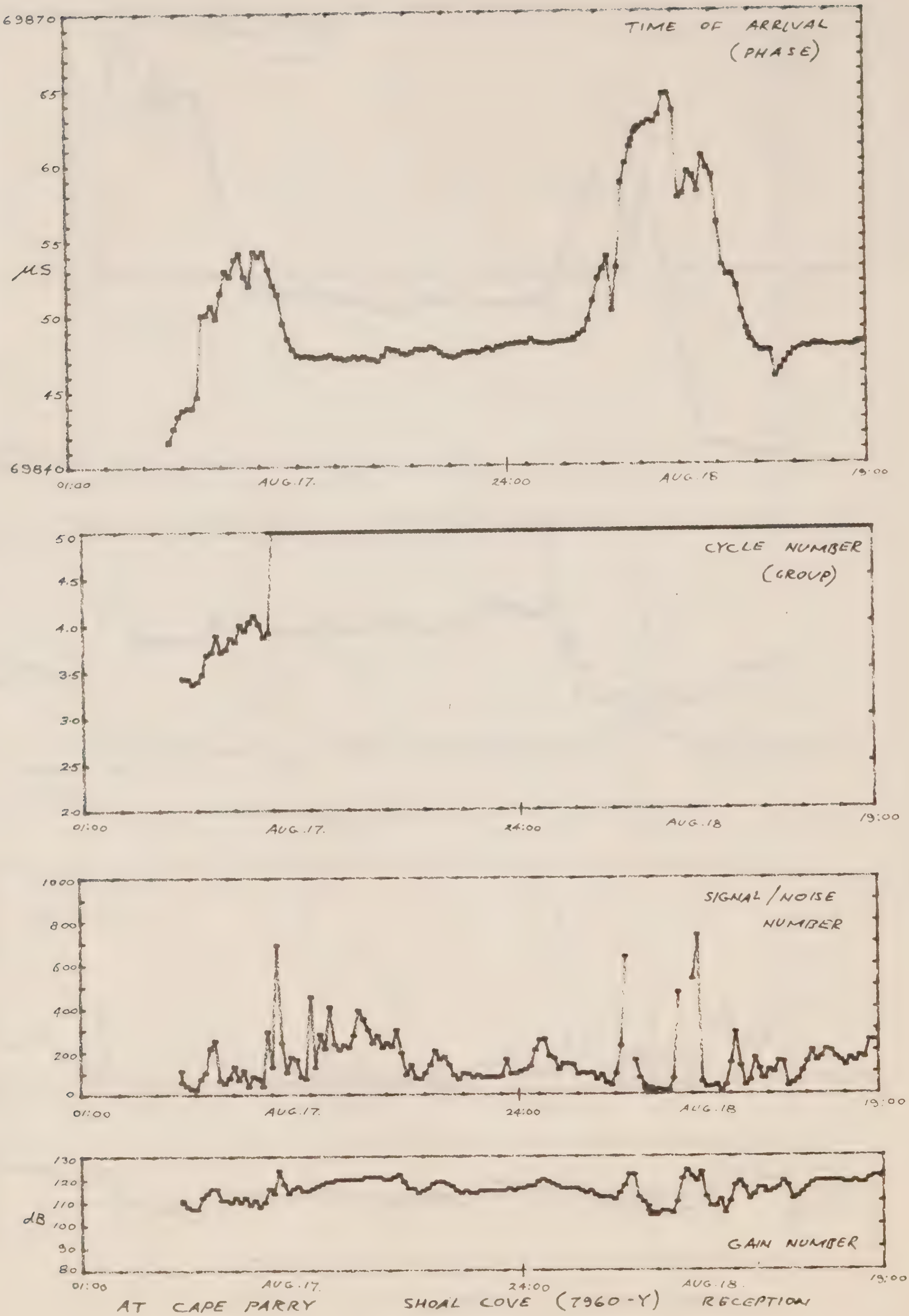
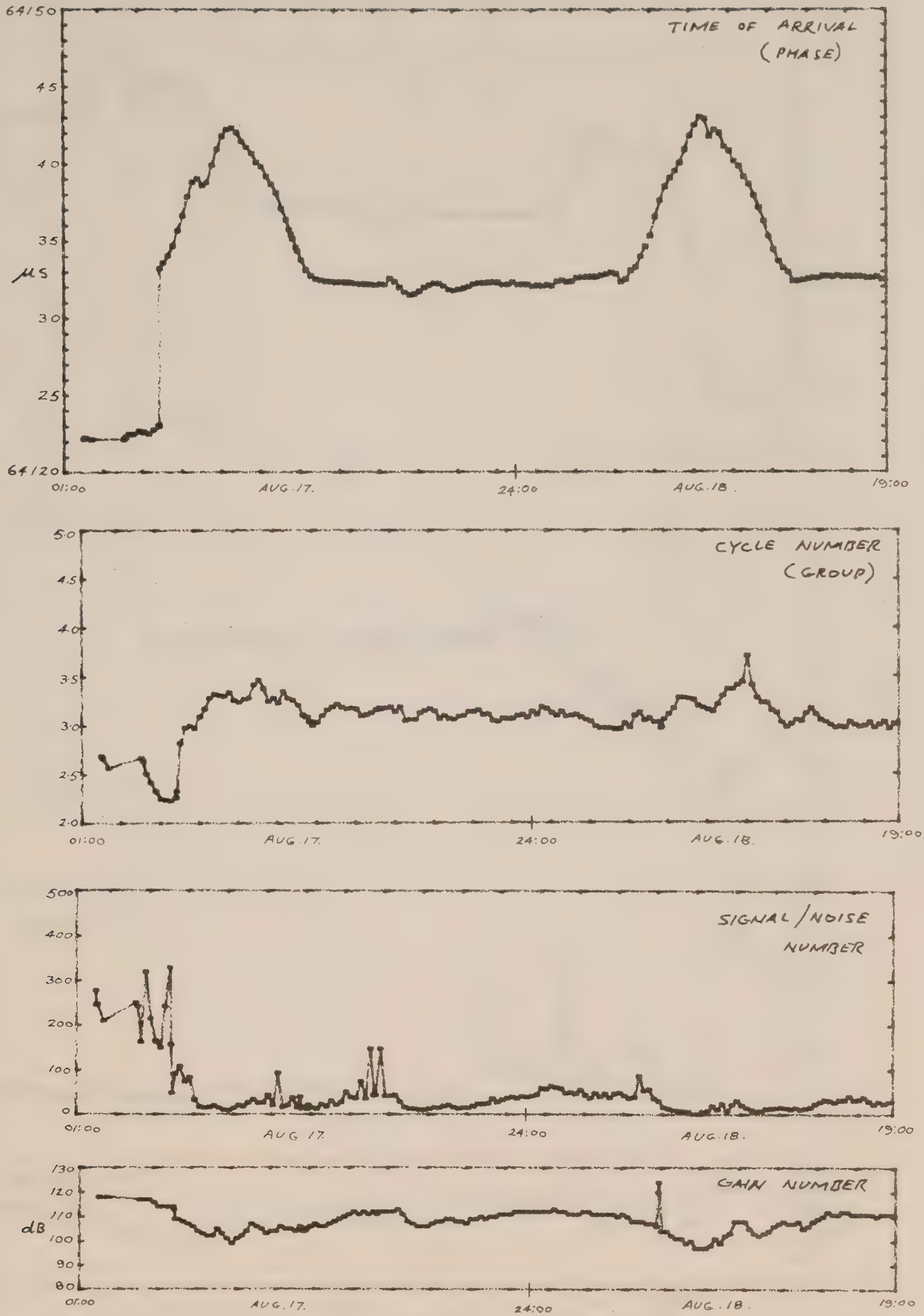

TIME OF ARRIVAL
(PHASE)
69870
65
60
55
μS
50
45
69840
01:00
AUG.17.
24:00
AUG.18
19:00
CYCLE NUMBER
(GROUP)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
01:00
AUG.17.
24:00
AUG.18
19:00
SIGNAL / NOISE
NUMBER
1000
800
600
400
200
0
01:00
AUG.17.
24:00
AUG.18
19:00
130
120
110
dB
100
90
80
GAIN NUMBER
01:00
AUG.17.
24:00
AUG.18.
19:00
AT CAPE PARRY SHOAL COVE (7960-Y) RECEPTION

Figure 17



AT CAPE PARRY PORT CLARENCE (9990-Y) RECEPTION

Figure 18

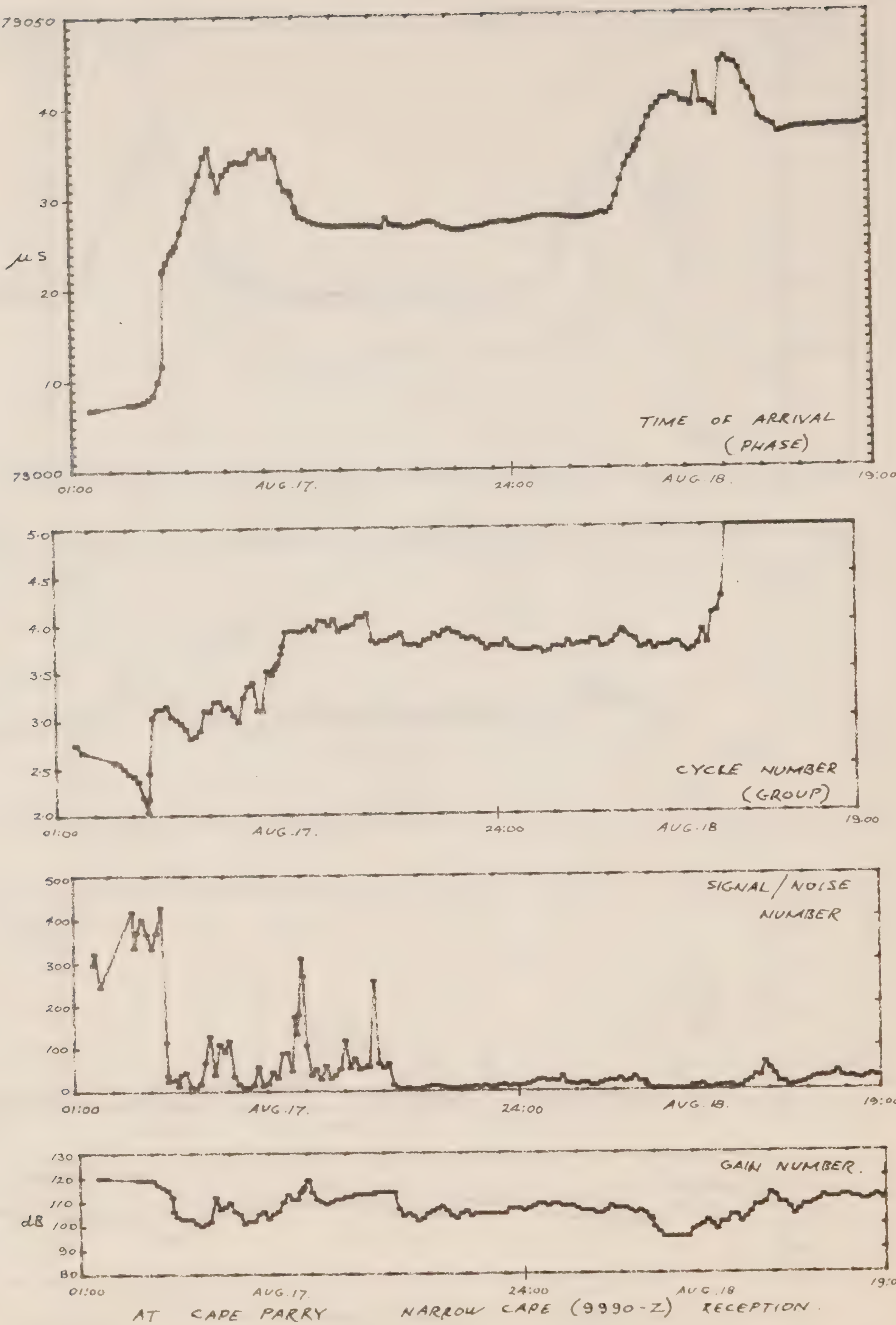

79050
40
30
μs
20
10
79000
TIME OF ARRIVAL
(PHASE)
01:00
AUG.17.
24:00
AUG.18.
19:00
5.0
4.5
4.0
3.5
3.0
2.5
2.0
CYCLE NUMBER
(GROUP)
01:00
AUG.17.
24:00
AUG.18
19.00
500
400
300
200
100
0
SIGNAL/NOISE
NUMBER
01:00
AUG.17.
24:00
AUG.18.
19:00
130
120
110
dB 100
90
80
GAIN NUMBER.
01:00
AUG.17.
24:00
AUG.18
19:00
AT CAPE PARRY NARROW CAPE (9990-Z) RECEPTION.

Figure 19

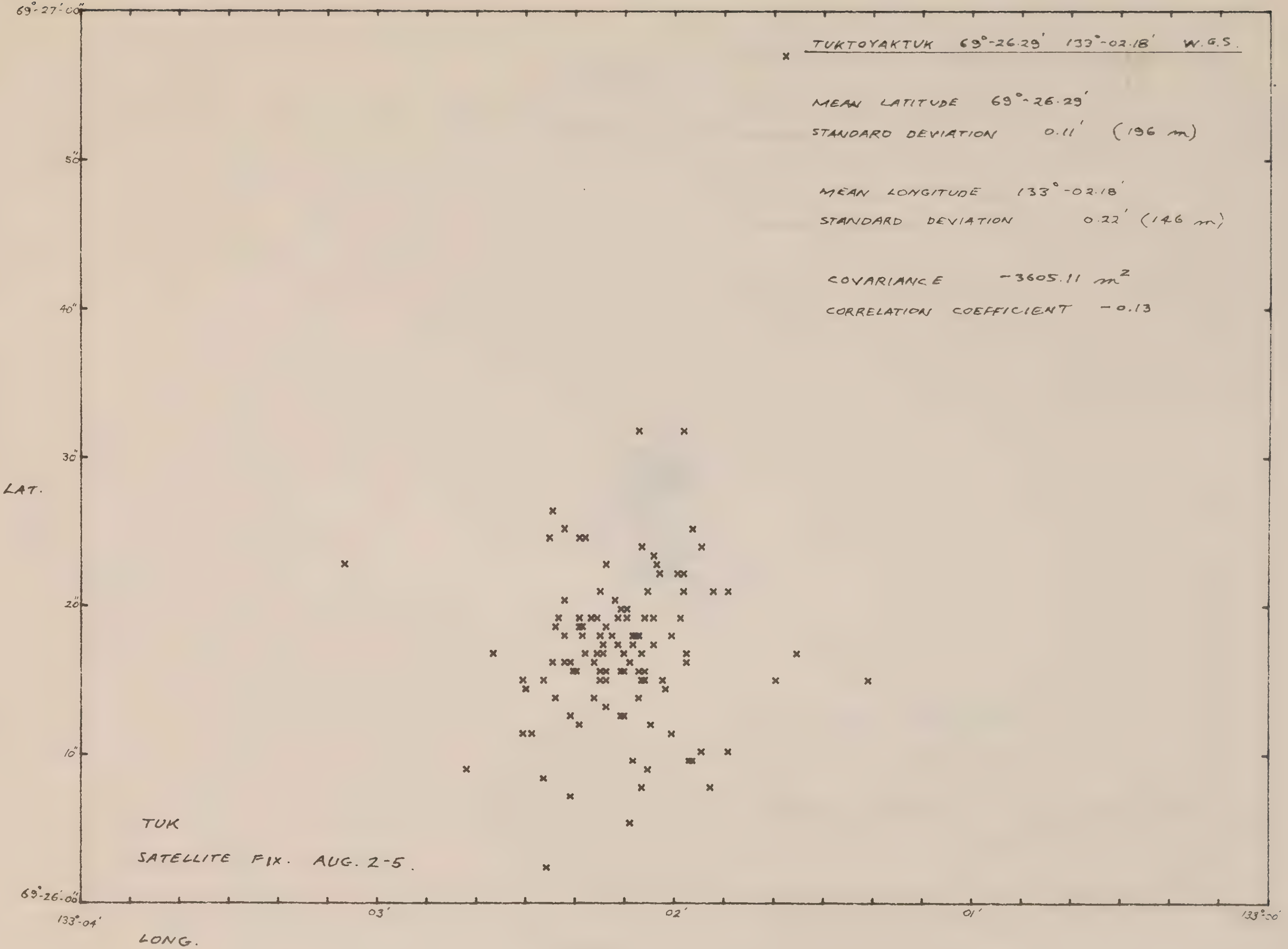

TUKTOYAKTUK 69°-26.29' 133°-02.18' W.G.S.
MEAN LATITUDE 69°-26.29'
STANDARD DEVIATION 0.11' (196 m)
MEAN LONGITUDE 133°-02.18'
STANDARD DEVIATION 0.22' (146 m)
COVARIANCE -3605.11 m²
CORRELATION COEFFICIENT -0.13
TUK
SATELLITE FIX. AUG. 2-5.
LAT.
LONG.
69°-27'-00"
50"
40"
30"
20"
10"
69°-26'-00"
133°-04'
03'
02'
01'
133°-00'

Figure 20

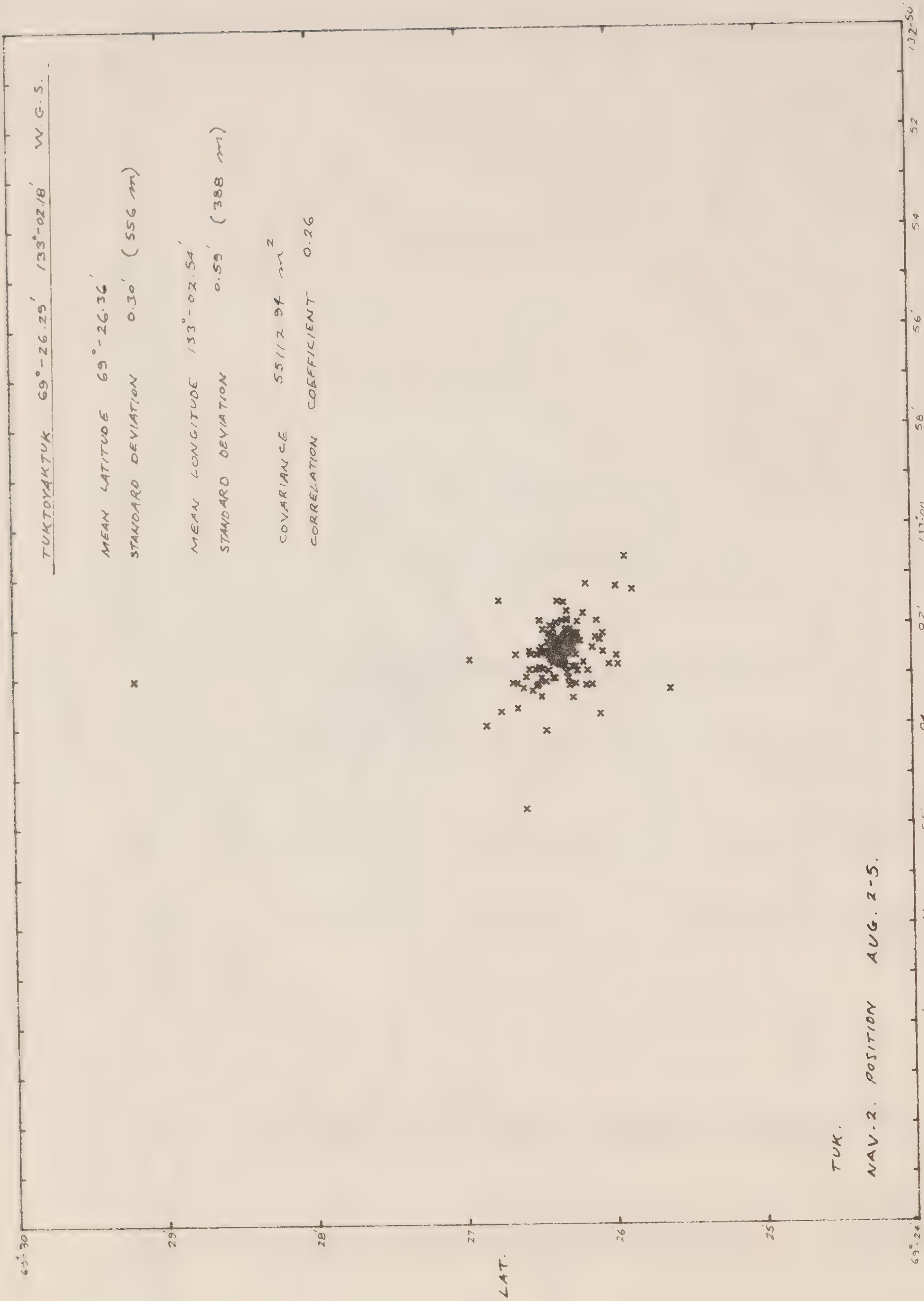

TUKTOYAKTUK 69°-26.29' 133°-02.18' W.G.S.
MEAN LATITUDE 69°-26.36'
STANDARD DEVIATION 0.30' (556 m)
MEAN LONGITUDE 133°-02.54'
STANDARD DEVIATION 0.59' (388 m)
COVARIANCE 55112 94 m²
CORRELATION COEFFICIENT 0.26
TUK.
NAV.2. POSITION AUG. 2-5.
LAT.
LONG.
132°50'
52
54
56'
58
133°00
02'
04
06'
08'
10'
12'
133°14'
69°30
29
28
27
26
25
69°24

Figure 21

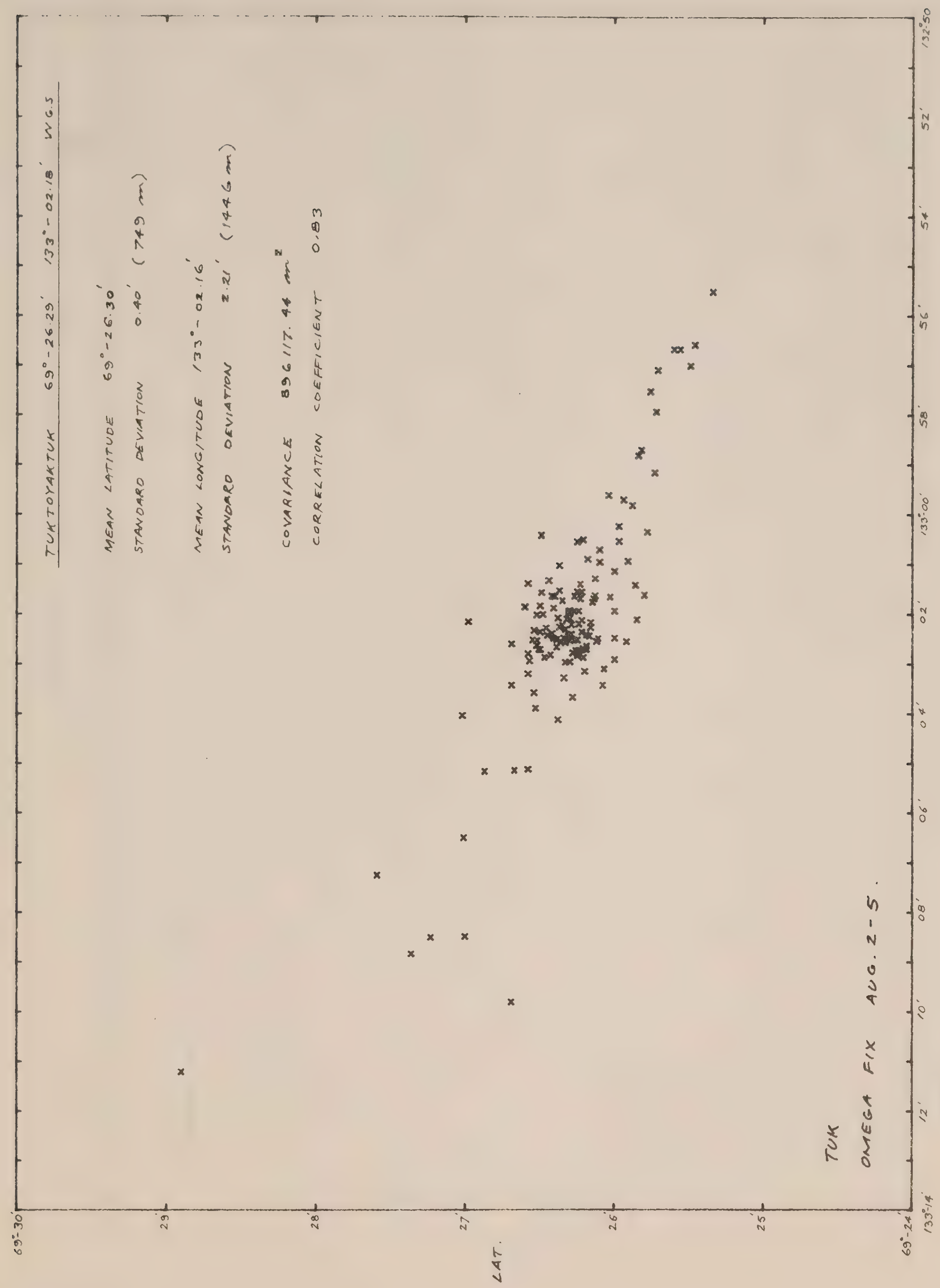

TUKTOYAKTUK 69°-26.29' 133°-02.18' WGS
MEAN LATITUDE 69°-26.30'
STANDARD DEVIATION 0.40' (749 m)
MEAN LONGITUDE 133°-02.16'
STANDARD DEVIATION 2.21' (1446 m)
COVARIANCE 896117.44 m²
CORRELATION COEFFICIENT 0.83
TUK
OMEGA FIX AUG. 2-5.
LONG.
LAT.
69°30'
29
28'
27'
26'
25
69°24'
133°14'
12'
10'
08'
06'
04'
02'
133°00'
58'
56'
54'
52'
132°50'

Figure 22

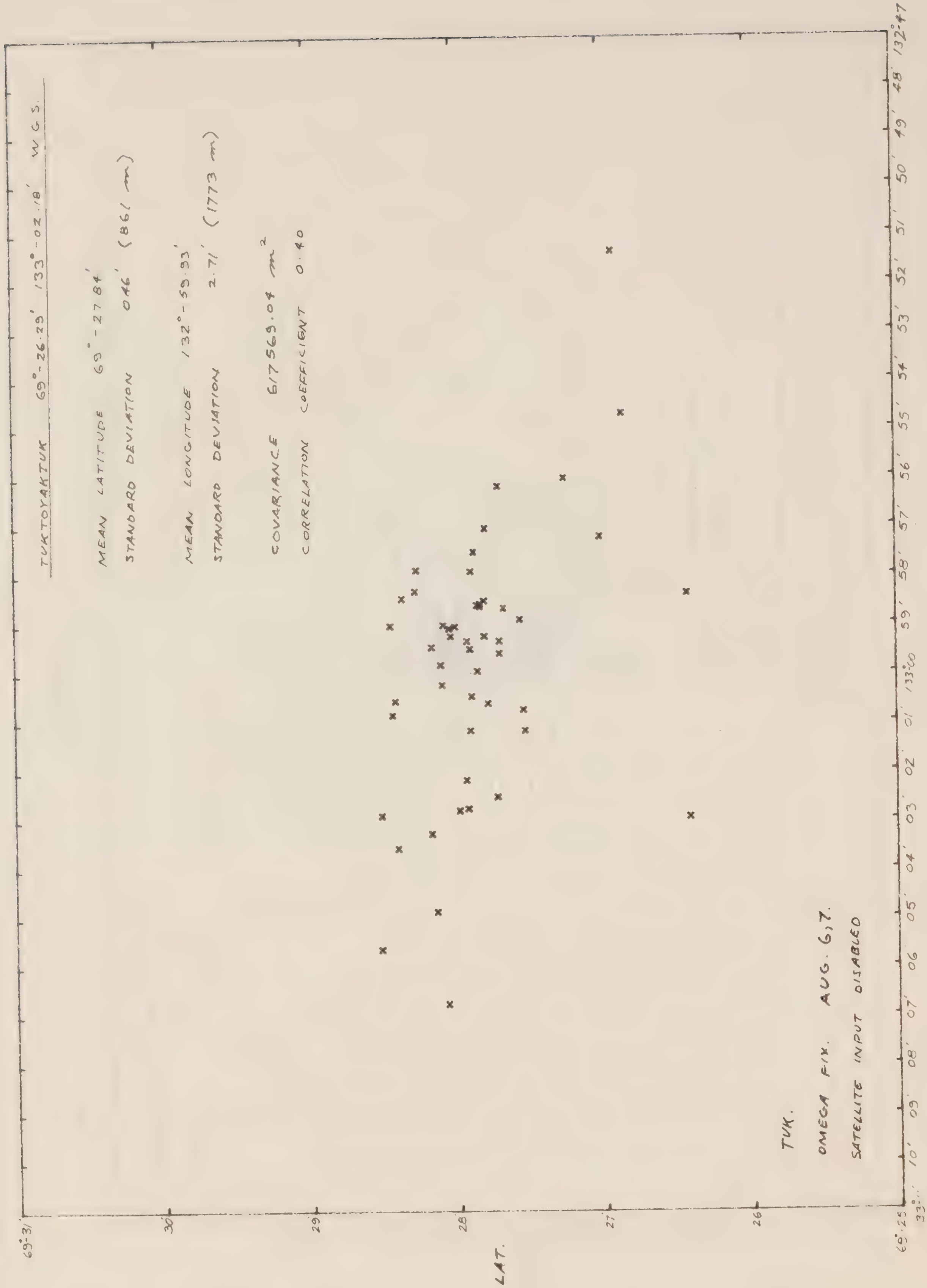

TUKTOYAKTUK 69°-26.29' 133°-02.18' W.G.S.
MEAN LATITUDE 69°-27.84'
STANDARD DEVIATION 0.46' (861 m)
MEAN LONGITUDE 132°-59.93'
STANDARD DEVIATION 2.71' (1773 m)
COVARIANCE 617569.04 m²
CORRELATION COEFFICIENT 0.40
TUK.
OMEGA FIX. AUG. 6,7.
SATELLITE INPUT DISABLED
LONG
LAT.
69°31'
30'
29'
28'
27'
26'
69°25'
133°
10'
09'
08'
07'
06'
05'
04'
03'
02'
01'
133°00
59'
58'
57'
56'
55'
54'
53'
52'
51'
50'
49'
48'
132°47'

Figure 23

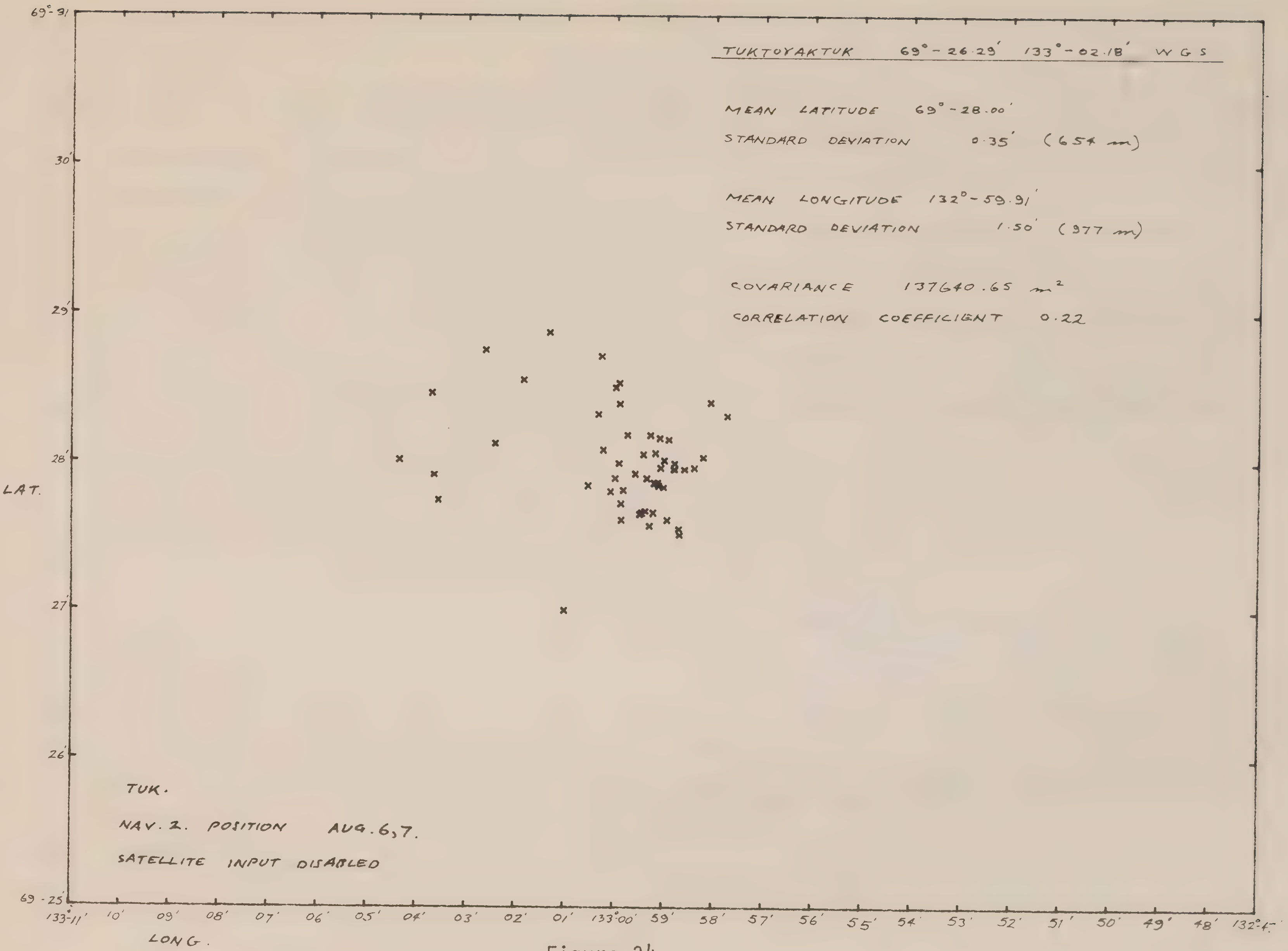
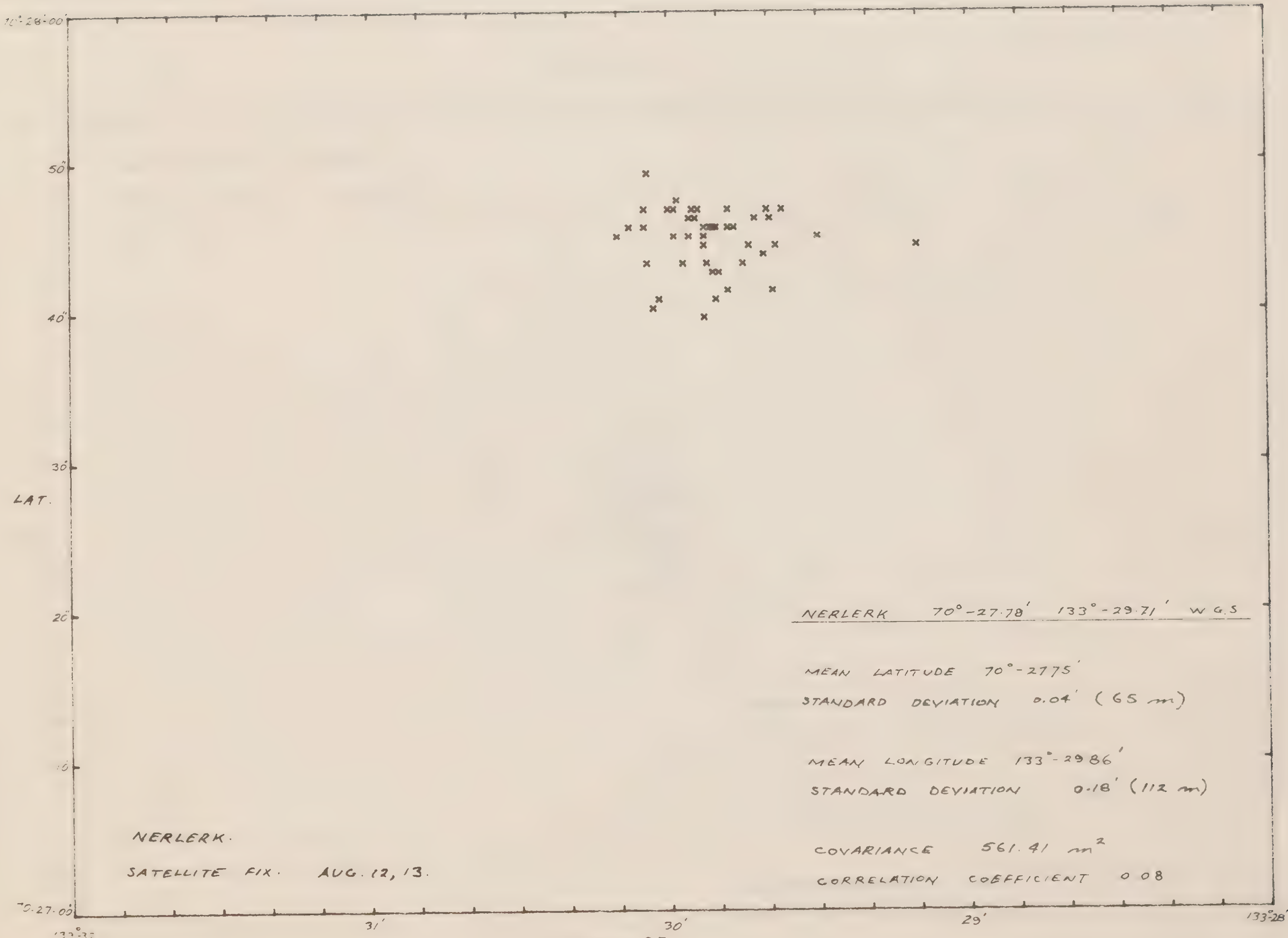

TUKTOYAKTUK 69° - 26.29' 133° - 02.18' WGS
MEAN LATITUDE 69° - 28.00'
STANDARD DEVIATION 0.35' (654 m)
MEAN LONGITUDE 132° - 59.91'
STANDARD DEVIATION 1.50' (977 m)
COVARIANCE 137640.65 m²
CORRELATION COEFFICIENT 0.22
TUK.
NAV. 2. POSITION AUG. 6,7.
SATELLITE INPUT DISABLED
69° 31
30'
29'
28'
27'
26'
69 - 25'
LAT.
133° 11'
10'
09'
08'
07'
06'
05'
04'
03'
02'
01'
133° 00'
59'
58'
57'
56'
55'
54'
53'
52'
51'
50'
49'
48'
132° 47'
LONG.

Figure 24



70°28·00
50"
40"
30"
LAT.
20"
10"
70°27·00
133°32
31'
30'
29'
133°28'
LONG.
NERLERK.
SATELLITE FIX. AUG. 12, 13.
NERLERK 70°-27·78' 133°-29·71' W.G.S
MEAN LATITUDE 70°-27·75'
STANDARD DEVIATION 0·04' (65 m)
MEAN LONGITUDE 133°-29·86'
STANDARD DEVIATION 0·18' (112 m)
COVARIANCE 561.41 m²
CORRELATION COEFFICIENT 0·08

Figure 25

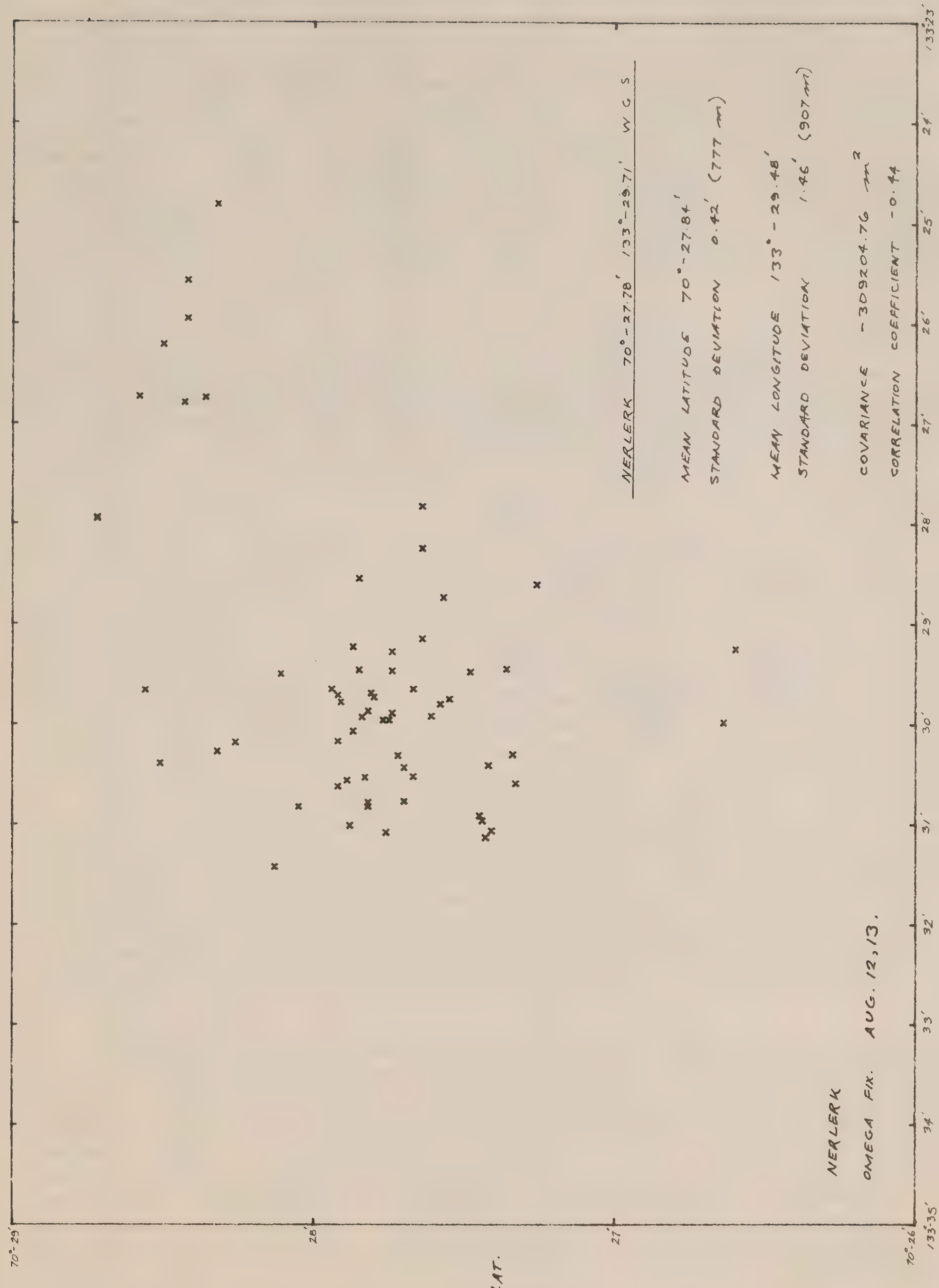

NERLERK 70°-27.78' 133°-29.71' WGS
MEAN LATITUDE 70°-27.84'
STANDARD DEVIATION 0.42' (777 m)
MEAN LONGITUDE 133°-29.48'
STANDARD DEVIATION 1.46' (907 m)
COVARIANCE -309204.76 m²
CORRELATION COEFFICIENT -0.44
NERLERK
OMEGA FIX. AUG. 12,13.
LONG.
LAT.
70°-29'
28'
27'
70°-26'
133°-35'
34'
33'
32'
31'
30'
29'
28'
27'
26'
25'
24'
133°-23'

Figure 26

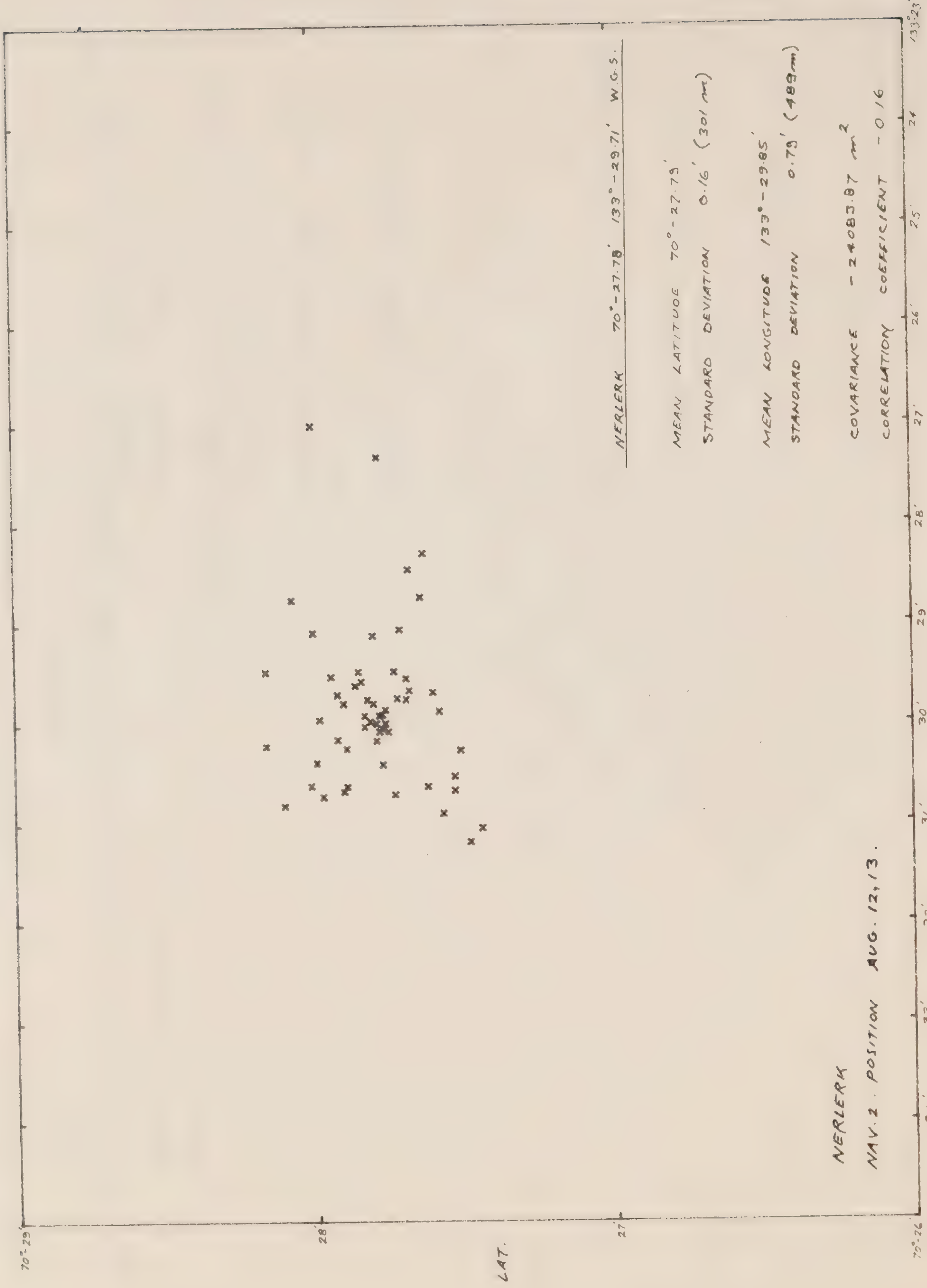

NERLERK 70°-27.78' 133°-29.71' W.G.S.
MEAN LATITUDE 70°-27.79'
STANDARD DEVIATION 0.16' (301 m)
MEAN LONGITUDE 133°-29.85'
STANDARD DEVIATION 0.79' (489m)
COVARIANCE -24083.87 m²
CORRELATION COEFFICIENT -0.16
NERLERK
NAV. 2 POSITION AUG. 12, 13.
LONG.
LAT.
70°29'
28'
27'
70°26'
133°35'
34'
33'
32'
31'
30'
29'
28'
27'
26'
25'
24'
133°23'

Figure 27

Table 1

Distances to Transmitters (in nautical miles)

Transmitter	Tuktoyaktuk	Nerlerk (*Exp.1*)	Cape Parry
Tok	435.87	481.54	591.35
Narrow Cape	882.04	920.68	1043.99
Shoal Cove	843.81	906.12	903.40
St. Paul Is.	1218.54	1230.74	1396.80
Port Clarence	813.29	808.12	985.42

The theoretical extreme usable ranges of the stations, assuming a receiver that will acquire the signal with a signal-to-noise ratio of 1/3, an average conductivity along the groundwave propagation path of 0.001 mhos/metre, and an atmospheric noise level of 55db above 1 microvolt per metre, are listed in Table 2.

Table 2

Theoretical Receivable Ranges (Groundwave)

Transmitter	Peak Power	Range
Tok	540 kw	540 nm
Narrow Cape	400 kw	520 nm
Shoal Cove	540 kw	540 nm
St. Paul Is.	275 kw	490 nm
Port Clarence	1000 kw	570 nm

As predicted, only the transmissions from Tok were received by groundwave propagation. At Cape Parry, 590 nm from Tok the signal was not acquired instantaneously as at the other monitoring sites. Therefore, it appears that approximately 600 nm is the maximum overland range of the Tok transmission to the Beaufort Sea area. This 600 nm range is slightly higher than the predicted 540 nm maximum range and may imply the possibility of slightly higher ground conductivities (0.001 mhos/metre) than were used in the prediction.

Using the gain measurements from the Austron 5000 monitor system, field strengths in the Beaufort Sea ranged from 110 microvolts/metre at Tuktoyaktuk down to 40 microvolts/metre at Cape Parry for the Tok signals. The noise numbers observed on our receiver seldom exceeded 250 at Tuktoyaktuk, 150 at Nerlerk (*Explorer 1*) and 100 at Cape Parry. So actual noise levels in the Beaufort Sea this August appeared to be fairly low, ranging from -20 db above 1 microvolt/metre to -10 db above 1 microvolt/metre. Diurnal variations in noise level were not detectable. Envelope-to-cycle-difference from the Tok transmission ranged from -2 to -3 microseconds at the monitor sites. Signal acquisition was satisfactory at the two western sites and tracking ability was good at all three sites.

Loran-C Skywave Reception

First hop Loran-C skywave transmissions have a theoretical maximum range of about 2300 nm. Therefore the Beaufort Sea should be well within skywave reception range of the Alaska Loran-C stations. However, the signals from St. Paul Is. (9990 - Master) were difficult to acquire at Tuktoyaktuk and Nerlerk, and were not acquired at all at Cape Parry. The St. Paul Is. transmitter has a peak power of 275 kw. It was also impossible to acquire the Shoal Cove signals at any of the monitor sites during day time, even though this station has a peak power of 540 kw.

Loran-C Reception from Narrow Cape

Narrow Cape transmissions were quickly acquired at Tuktoyaktuk and at Nerlerk. They were tracked reasonably steadily at all three sites, although cycle skips occurred on most nights when the signals were monitored. Figures 4, 8, and 10 show a correlation of change in T.O.A. and the variation in measured E.C.D. as the ionospheric height rises and falls at sunset and sunrise. A diurnal variation is also seen in the gain and noise data.

Shoal Cove Reception

This station has a north-south propagation path to the Beaufort Sea and consistent tracking of Shoal Cove signals is difficult. Two or three cycle shifts were noted each night. At Nerlerk and at Cape Parry the monitor system could only erratically indicate a cycle number. Signal to noise measurements and receiver gain numbers indicated a weak signal. At Tuktoyaktuk large diurnal variations in E.C.D. were noted as the ionosphere changed height. It was possible to track third cycle of this signal for only one daylight period at Tuk.

St. Paul Is. Reception

At Tuktoyaktuk and at Nerlerk the St. Paul Is. signals were tracked quite steadily. Cycle skips occurred on one night at Tuktoyaktuk and one of the two nights at Nerlerk. E.C.D. at Tuktoyaktuk showed a marked correlation to shifts in ionospheric height. At Nerlerk, E.C.D. measurements also show this correlation although the logging period was limited. Signal to noise and receiver gain data indicate a weak signal; and as it was not possible to monitor this signal at Cape Parry it is assumed its range limit is somewhere around Longitude 132^{o}W.

Port Clarence Reception

The east-west path from Port Clarence to the Beaufort Sea provides good skywave propagation conditions. A stable signal was received at all three monitoring sites.

Only one cycle skip occurred during the monitoring periods at Nerlerk and one at Cape Parry. The E.C.D. measurements show a distinct dip as the ionosphere rises at sunset. There is a slight recovery in E.C.D. during the night; then there is another distinct dip at sunrise as the ionosphere returns to daytime levels. This effect is seen best in the data collected at Tuktoyaktuk in Figure 7. Signal/noise and gain data indicate the Port Clarence signal was the strongest and most stable of the available skywave signals. The path from Port Clarence to the Beaufort Sea does not experience complete night effect during early August. Therefore, the change in ionospheric height will probably be less that for the other transmission paths monitored.

Skywave E.C.D. and T.O.A. Variation

As noted earlier, when the T.O.A. of a Loran-C transmission is delayed due to a rise in ionospheric height, the E.C.D. changes. Therefore, it may be possible to use E.C.D. measurements to predict change in T.O.A., assuming E.C.D. does not change due to other causes within the limited area of interest to the operator. The relationships of E.C.D. to changes in T.O.A. can be seen in Figure 32. If, an E.C.D. measurement could be used to predict change T.O.A. it would be independent of time and estimates of ionospheric height. Thus the use of skywave Loran-C position lines could be extended to the periods after sunset and before sunrise when the ionosphere is moving rapidly. A simple quadratic model, based change of E.C.D. per hour, gives the absolute value of change of T.O.A. for the next hour.

$$|\Delta T_{i+1}| = -0.15(\Delta C_i) + 0.38(\Delta C_i)^2$$

where ΔC_i = change of E.C.D. during the preceding hour

ΔT_{i+1} = predicted change of T.O.A. during the forthcoming hour.

This model was based on the nice data from the Port Clarence transmissions received at Tuktoyaktuk. When used to predict changes of T.O.A.s for other transmissions, it produces estimates with rms errors of about ±1 microsecond per hour. If E.C.D. measurements are to be used as predictions for T.O.A. changes, obviously a physical explanation will be required for the relationship. It may then be possible to derive a general and more accurate model.

Skywave Propagation Corrections

Several authors have reported on skywave propagation models that predict phase lags and their diurnal and seasonal variations. These works are reviewed in Reference 2. For low frequencies, 70 to 245 Khz, Belrose estimates that the effective heights of ionospheric reflection are about 90 km at night and 72 km by day, at ranges in the order of 1000 km (3). Davies (Ref. 2, p.418) gives the following equation to relate phase change to height change

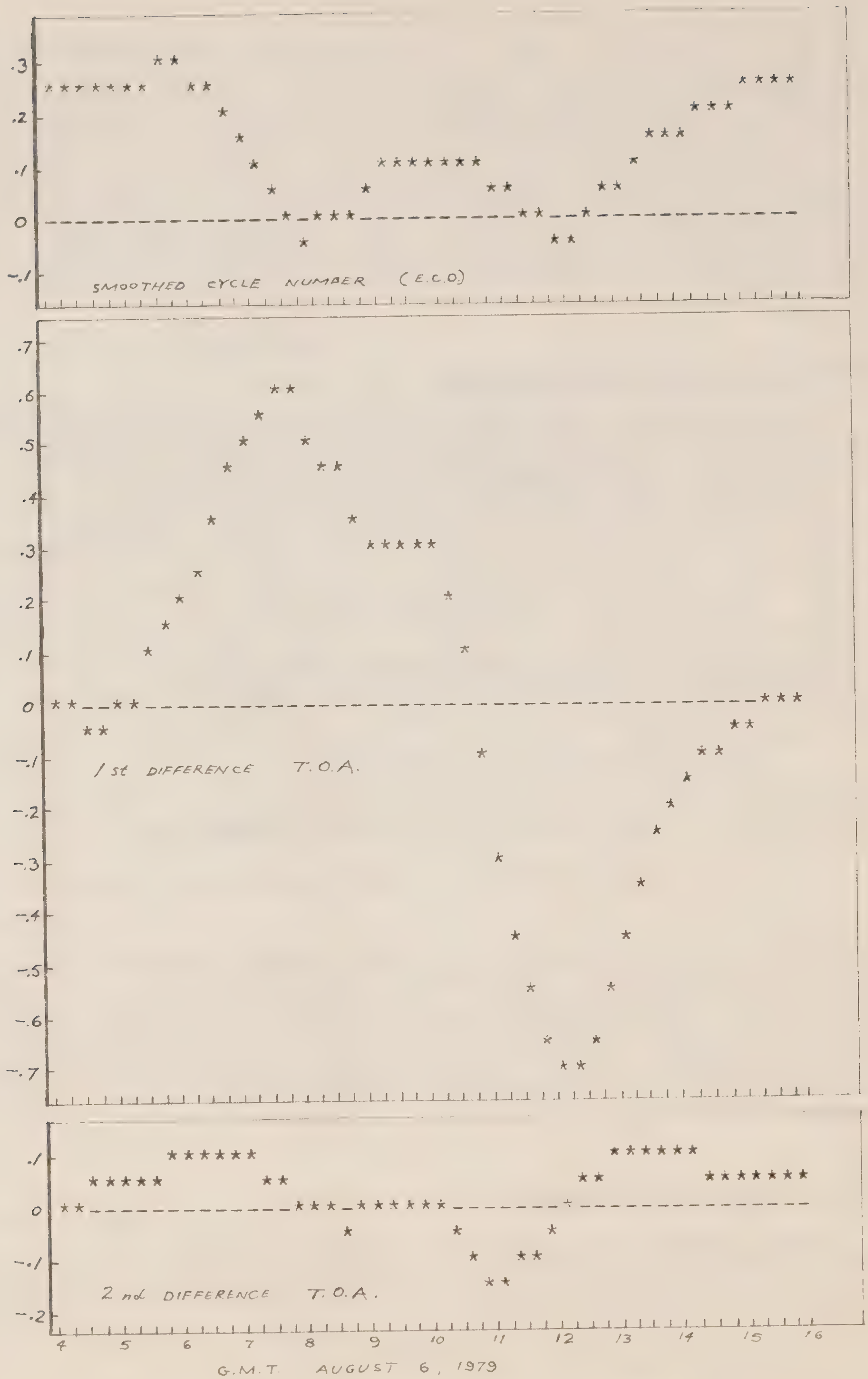

.3
.2
.1
0
-.1
SMOOTHED CYCLE NUMBER (E.C.O.)
.7
.6
.5
.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
1st DIFFERENCE T.O.A.
.1
0
-.1
-.2
2nd DIFFERENCE T.O.A.
4
5
6
7
8
9
10
11
12
13
14
15
16
G.M.T. AUGUST 6, 1979

Figure 32

$$\Delta\phi = 2\pi d \left[\frac{h}{2a} + \frac{\lambda^2}{16h^2} \right] \frac{\Delta h}{h} \quad \text{radians}$$

where $\Delta\phi$ = phase change in radians

d = distance, transmitter to receiver (km)

h = mean ionospheric height (km)

Δh = height change (km)

λ = wavelength (km)

a = earth radius (6371 km)

With specific reference to Loran-C, Doherty in Reference 4 found phase changes equivalent to a 22 km apparent height change when working in the Bering Sea. Work in Norway, described in Reference 5 (Larsen and Thrane) reports that effective reflection heights for Loran-C pulses to be between 50 and 60 km during the day and about 83 km at night, for a range of 300 km. It appears that Larsen and Thrane calculate only a slight change in effective height with range.

Automated Offshore Navigation Inc., referred to by D. Livingston (Bedford Institute of Oceanography, Dartmouth, N.S.) in Reference 6, gives a geometric model to predict skywave phase delays.

$$\Delta d = \frac{91-59}{2} \quad \mathrm{Sin} \left\{ 2.\arctan \left[\frac{91+6371\cdot(1-\mathrm{Cos}\ \Theta)}{6371\cdot\mathrm{Sin}\ \Theta} \right] \right\}$$

where $\Theta = 4.5\ .10^{-3}.D$

D = distance (km)

and Δd = delay in km due to ionospheric shift from 59 to 91 km.

The United States Defense Mapping Agency uses another formula to compute Loran-C skywave delays.

(a) $$D' = \frac{N}{C} \left[2 \sqrt{(h^2 + 4a(a+h)\ \sin^2\left(\frac{S}{4Na}\right)} - \frac{S}{N} \right] \qquad 0 \leqslant S \leqslant NS\ max$$

(b) $D = D' - d$

where D = Total Skywave Delay in microseconds

D' = Principal part of the Nth hop skywave delay in microseconds

$d = -0.3 + 0.00208S \qquad 0 \leqslant S \leqslant NS\ max$

$d = -0.3 + 0.00208NS\ max \qquad NS\ max < S$

N = Number of hops

C = Velocity of light = $299.792458 \times 10^{-3}$ km/microsecond

h = Apparent height of the ionosphere in kilometres
91 kilometres (night) and 73 kilometres (day)

a = Effective earth radius = 8490 kilometres

S = Groundwave path length in kilometres

S max $2\sqrt{2ah}$

NS max $N(2\sqrt{2ah})$

When NS max < S the value of D' becomes a constant formula (a) becomes:

$$D' = \frac{N}{C}\left[2\sqrt{h^2 + 4a(a+h)\sin^2\left(\frac{S\ max}{4Na}\right)} - \frac{S\ max}{N}\right]$$

Loran-C Diurnal T.O.A. Changes

The observed changes in Loran-C T.O.A.s due to change in ionospheric height are listed in Table 3.

Table 3

Loran-C Diurnal Phase Changes (in microseconds)

	7960X	7960Y	9990M	9990Y	9990Z
At Tuktoyaktuk.					
Obs. Night 1	11.7	11.8	8.8	8.0	13.1
" " 2	12.0	12.5	8.2	7.3	13.2
" " 3	11.0	9.3	8.6	6.7	12.9
At Nerlerk, CANMAR *Explorer 1.*					
Obs. Night 1	13.2	7.8	-	7.8	13.6
" " 2	16.6	8.7	11.8	8.9	13.0
" " 3	16.2	9.2	13.6	10.4	11.7
Predicted (N.B.S.)	8.1	8.0	10.9	7.1	8.1
" (D.M.A.)	17.4	17.5	-	18.2	17.4

The two predictions for Nerlerk are based on the National Bureau of Standards (N.B.S.) (Reference 4) and the Defense Mapping Agency (D.M.A.) (see page 28) methods. Ionospheric heights are assumed to be 73 km in the day and 91 km at night, thus the change in height is 18 km. The observed shifts fall between the two predictions, but are generally closer to the N.B.S. method. Using average observed phase changes, the height changes can be computed from Reference 4, p.414.

$$\Delta h = \Delta\phi \frac{\lambda}{2\pi}\sqrt{\frac{d^2+h^2}{2h}}$$

where Δh = change in ionospheric height (km)
$\Delta\phi$ = observed phase shift (radians)
h = mean height (km)

2d = ground distance (km)
λ = wave length (km)

The changes, in the height of the ionosphere between day and night are given in Table 4.

Table 4

Estimated Change of ionsopheric Height (in km)

	7960X	7960Y	9990M	9990Y
At Tuktoyaktuk	17.4	16.1	17.7	10.2
At Nerlerk	24.0	13.2	26.5	12.4

The observations of diurnal phase shift show a wide variation in the changes in ionospheric heights.

An attempt was made at Cape Parry to measure the difference between the T.O.As of the ground and skywaves from Tok. The difference in T.O.A. from short period at the middle of the night was 51.5 ± 1.1 microseconds. The difference, predicted by the D.M.A. method, is 54.1 microseconds.

As can be seen from all the T.O.A. data collected, the ionosphere is only stable during the summer night for a very short period. The ionosphere starts to rise immediately after sunset at the receiver. As all the transmitters used were to the west of the test area, the signals do not stabilize until well after local sunrise at the receiver. There are only 14 hours of stable signal availability, during August, which is the peak of the operational season in the Beaufort Sea. This time, of course, decreases as winter approaches.

Loran-C Position Lines

Two types of position lines can be generated by a Loran-C chain. T.O.A.'s can be used as ranges from the transmitters if a precise frequency standard is available, and if synchronization corrections are applied to the T.O.A.'s to reduce them to ranges. The observed stability (daytime) of the T.O.A.'s from the transmissions available in the Beaufort Sea is listed in Table 5.

Table 5

Daytime T.O.A. Stability

(Standard deviation in microseconds)

	Groundwave	Skywave				
	7960-M	7960-X	7960-Y	9990-M	9990-Y	9990-Z
At Tuktoyaktuk	0.05	0.27	0.32	0.42	0.44	0.37
At Nerlerk (*Expl. 1*)	0.06	0.56	0.35	0.25	0.44	0.92
At Cape Parry	0.03	0.30	0.56	-	0.28	0.29

As the nights in August are so short the ionosphere does not settle at a higher altitude for any length of time. Therefore, it is not possible to estimate accurately the stability of T.O.A.'s at night. The instability for T.O.A.'s during the brief period when the ionosphere is at its highest level appears to be about two to three times greater than that observed during the day.

The correlations between T.O.A. errors appear to be relatively high. Typical observed correlations are tabulated in Table 6 for daylight hours.

Table 6

T.O.A. Correlations

	7960M	X	Y
7960M	1	0.40	0.13
X	0.40	1	0.73
Y	0.13	0.73	1
	9990M	Y	Z
9990M	1	0.93	0.99
Y	0.93	1	0.95
Z	0.99	0.95	1

The effect of skywaves on the T.O.A. errors is clearly seen in the above table.

In daytime, a fix using Loran-C T.O.A.'s (precisely synchronized) should have a radial error of ±500 m (1 sigma confidence level) or less, depending on the number of position lines used.

Four Loran-C time differences are available in the western Beaufort Sea. The estimates of the errors associated with these hyperbolic position lines are listed in Table 7. The data sets used to generate Table 7 are independent of those used for Tables 5 and 6.

Table 7

Daytime T.D. Stability
(Standard deviation in microseconds)

	Tuktoyaktuk	Nerlerk	Cape Parry
7960X	0.27	0.52	0.29
y	0.14	0.35	0.24
9990Y	0.16	0.28	-
Z	0.27	0.33	-

So, if accurate skywave corrections were possible, a Loran-C hyperbolic fix, taken about 60 nm north of Tuktoyaktuk should have an accuracy of ±3 km for the Gulf of Alaska Chain (7960) and ±1.5 km from the Bering Sea Chain (9990). Due to uncertainties in skywave measurements the above accuracy

estimates should probably be doubled.

Omega Reception

Reference 7 (Vass) predicts that Omega stations A (Norway), C (Hawaii), D (North Dakota) and H (Japan) will be received in the Beaufort Sea, during summer daylight with adequate signal-to-noise ratio and insignificant modal interference. Figures 28 and 29 show the Omega stations used by the MX1105 system, and those with low signal strength, at our two monitor sites at Tuktoyaktuk and Nerlerk (*Explorer 1*). These data confirm the predictions, except that H (Japan) at Tuktoyaktuk was not used continuously as its signal-to-noise ratio intermittently dropped below that acceptable for fixing. The MX1105 uses a pseudo-ranging technique for positioning that requires signals from at least three stations. This number of required signals was available throughout the monitoring period at both sites with the exception of one overnight period at Nerlerk.

On this occasion the Omega section of the MX1105 system did, what can best be described as, "latch-up". After two hours the receiver re-synchronized on Omega stations C (Hawaii), D (North Dakota), and G (Trinidad), but exhibited low signal-to-noise ratios for A (Norway) and H (Japan). During this period poor positions were produced by the system. Five hours later the MX1105 "latched-up" again, but after a further two hours re-synchronized on the usual four stations A, C, D, H. It is difficult to find the causes for this one failure of the MX1105 system. This failure can probably be attributed to external reception conditions rather than an intermittent receiver fault.

United States Coast Guard, through the Canadian Coast Guard made available some data from their Omega monitor station at Inuvik Airport. Regrettably the monitor was not working when our measurements were made in the Beaufort Sea. However, the monitor data from Inuvik, covering a short period from Aug. 21st to Aug. 23rd confirmed to some extent our data from Tuktoyaktuk and *Explorer 1*. During this short period the monitor tracked Omega station A (Norway), C (Hawaii) and H (Japan) reliably. Omega station D (North Dakota) was not tracked during this period as it was down for maintenance. Table 8 gives the range of signal-to-noise ratio and number of cycle skips experienced during this short period.

Table 8

Omega Monitor - Inuvik (34 hrs only)
Signal-to-Noise Range (db)

	High	Low	# of times cycle skips occurred
A	0	-70 approx.	2
C	3	-33	1
D	not operational	------------	------------
H	-5	-70 approx.	5

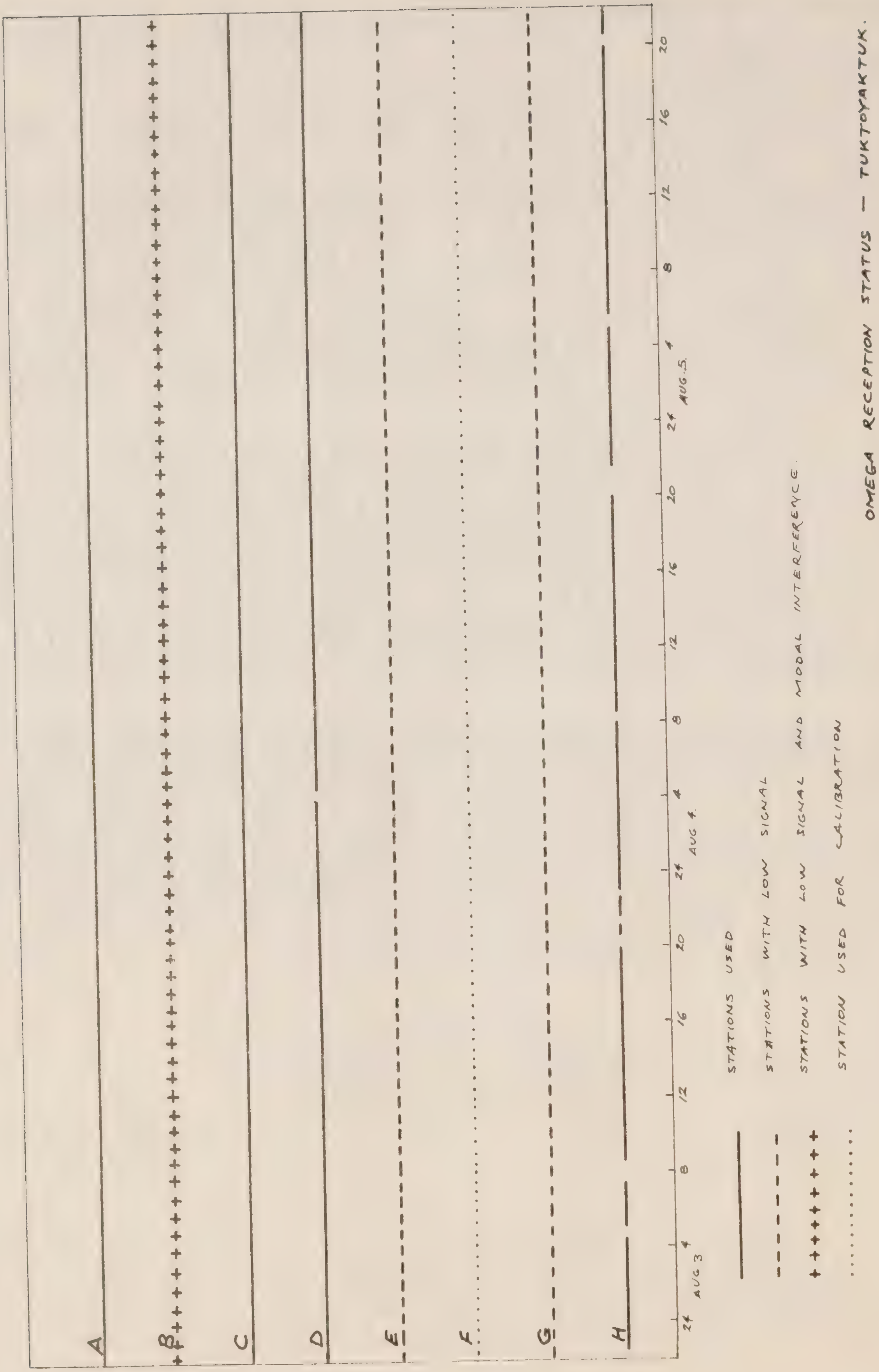

A
B
C
D
E
F
G
H
24
AUG 3
4
8
12
16
20
24
AUG 4
4
8
12
16
20
24
AUG 5
4
8
12
16
20
STATIONS USED
STATIONS WITH LOW SIGNAL
STATIONS WITH LOW SIGNAL AND MODAL INTERFERENCE
STATION USED FOR CALIBRATION
OMEGA RECEPTION STATUS — TUKTOYAKTUK.

Figure 28

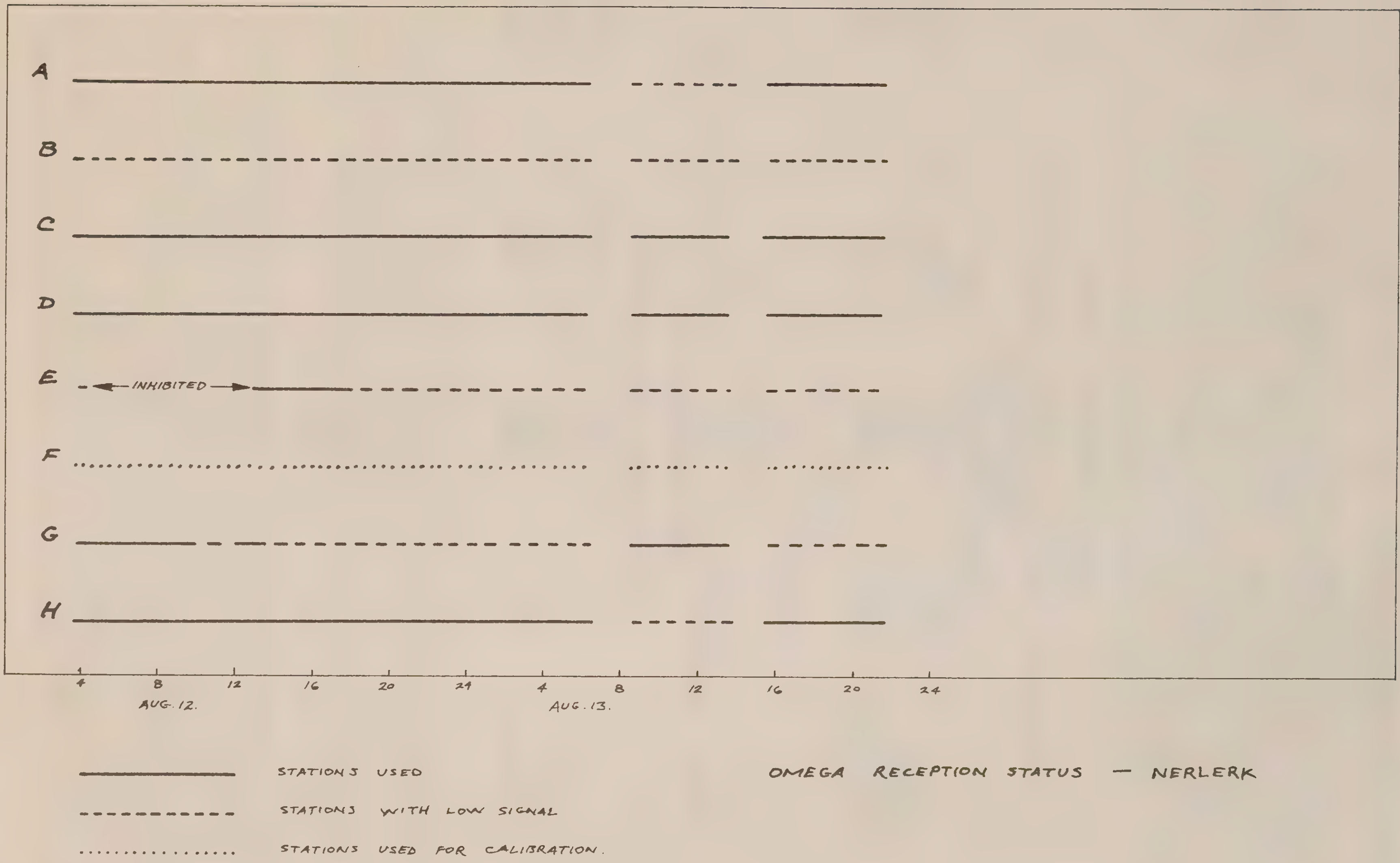

A
B
C
D
E
INHIBITED
F
G
H
4
8
12
16
20
24
4
8
12
16
20
24
AUG. 12.
AUG. 13.
STATIONS USED
STATIONS WITH LOW SIGNAL
STATIONS USED FOR CALIBRATION.
OMEGA RECEPTION STATUS — NERLERK

Figure 29

Integrated Satnav/Omega Positions

The MX1105 Satellite/Omega navigator produces four estimates of position (1) Single Channel Satnav fixes, (2) Omega stand-alone fixes (3) Integrated Satnav and ships gyro and speed log positions (Nav. 1) and (4) integrated Satnav and Omega positions (Nav. 2). All position data were collected with the receiver stationary, therefore Nav. 1 positions are not relevant to our measurements. The estimates of the errors associated with the other types of position are given in Tables 9 and 10 for Tuktoyaktuk and *Explorer 1* respectively.

Table 9

Tuktoyaktuk - Overall Omega/Satnav Accuracies from MX1105 Receiver

Standard Deviations in metres

	Lat.	Long.	Radial	Correlation
Satnav.	196	146	244	-0.13
Omega	749	1446	1628	+0.83
Integrated	556	388	678	+0.26

Table 10

Nerlerk - CANMAR *Explorer 1* - Overall Omega/Satnav Accuracies from MX1105 Receiver

Standard Deviations in metres

	Lat.	Long.	Radial	Correlation
Satnav.	65	112	130	+0.08
Omega	777	907	1194	-0.44
Integrated	301	489	574	-0.16

Also, as the measurements were made with the MX1105 stationary, additional errors in Satnav positions are to be expected on a moving ship. These errors in the Satnav position will propagate through to increase the errors in both the integrated and Omega positions. However, if both ship's log and gyro, and Omega are available for velocity input to the Satnav fixes then this increase in error should not be excessive.

Figure 30 shows the stability of the Omega and integrated positions at Tuktoyaktuk by their latitude and longitude co-ordinates. The initial variations, seen at the left of the graphs show the settling effect immediately after startup of the equipment. Diurnal variations in the accuracy of the Omega signals are also apparent. These variations, due to changing day and night propagation conditions are not carried through, to any great extent, to the integrated (Nav. 2) positions. These diurnal changes in error, and the lack of them for the integrated position, are tabulated in Table 11. Figure 31 shows the stability of the co-ordinates produced by

the MX1105 when used as a stand-alone Omega receiver. Two features are discernible from these graphs (1) the effect of the smoothing introduced by the integration algorithm and (2) the constant offset of about 2 minutes of latitude and 2 minutes of longitude, when compared to the true position, due probably to inaccuracies in the Omega propagation models used. The observed errors and constant offsets for the stand-alone Omega data are given in Table 12.

Table 11

Diurnal Variations in Accuracies from MX1105 Receiver

Standard Deviation in metres

Day	Lat.	Long.	Radial	
			Omega - Night	
Aug.3	1321	2602	2918	(Start up)
4	663	1388	1538	
5	580	1260	1387	
R.M.S.			1464	(Start up excluded)
			Integrated - Night	
3	1046	318	1093	(Start up)
4	311	213	377	
5	262	482	548	
R.M.S.			470	(Start up excluded)
			Omega - Day	
3	233	371	438	
4	432	566	712	
5	378	464	598	
R.M.S.			593	
			Integrated - Day	
3	125	329	352	
4	344	451	567	
5	364	344	500	
R.M.S.			481	

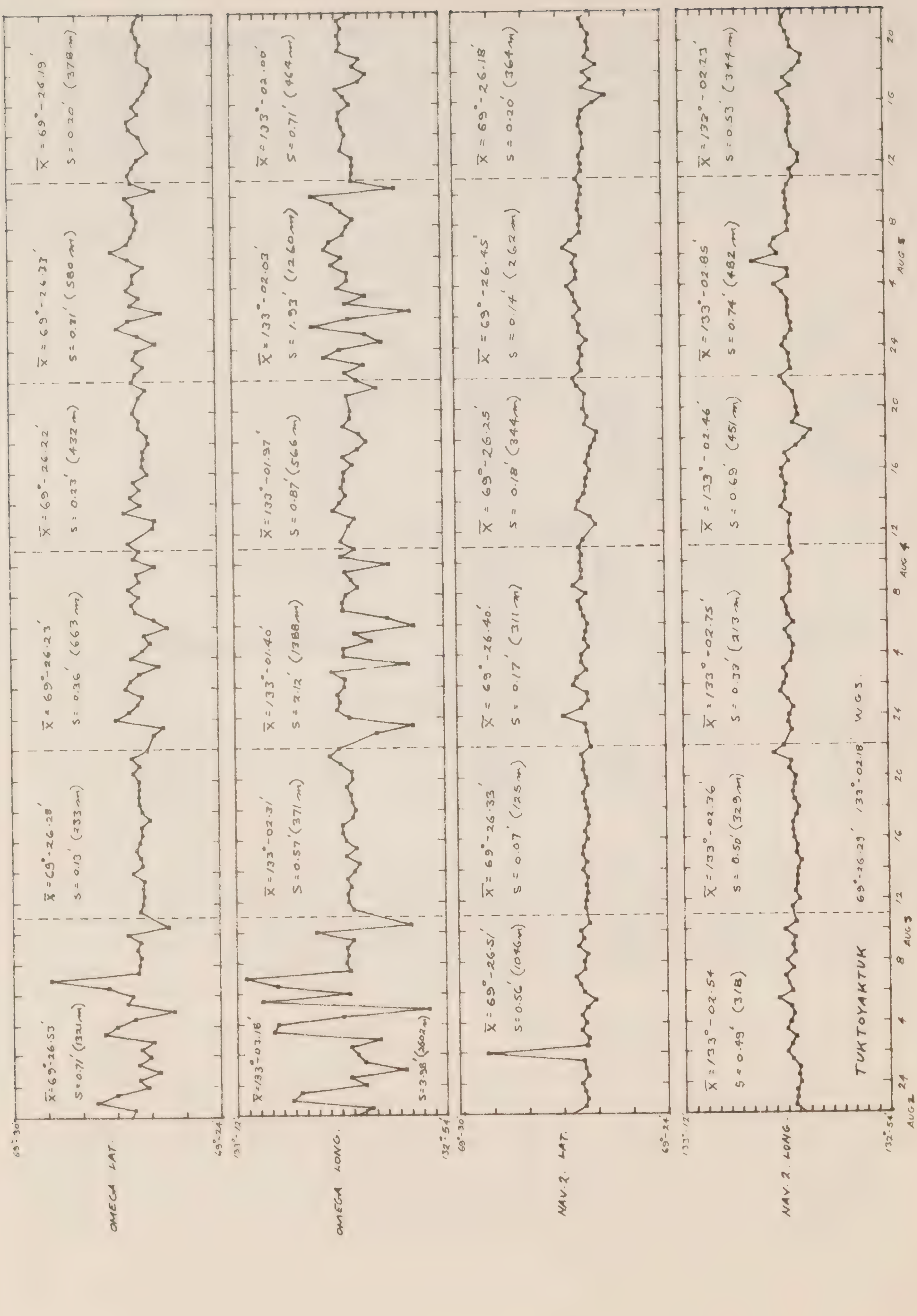

OMEGA LAT.
OMEGA LONG.
NAV. 2. LAT.
NAV. 2. LONG.
TUKTOYAKTUK
69°-26.29' 133°-02.18' WGS.

Figure 30

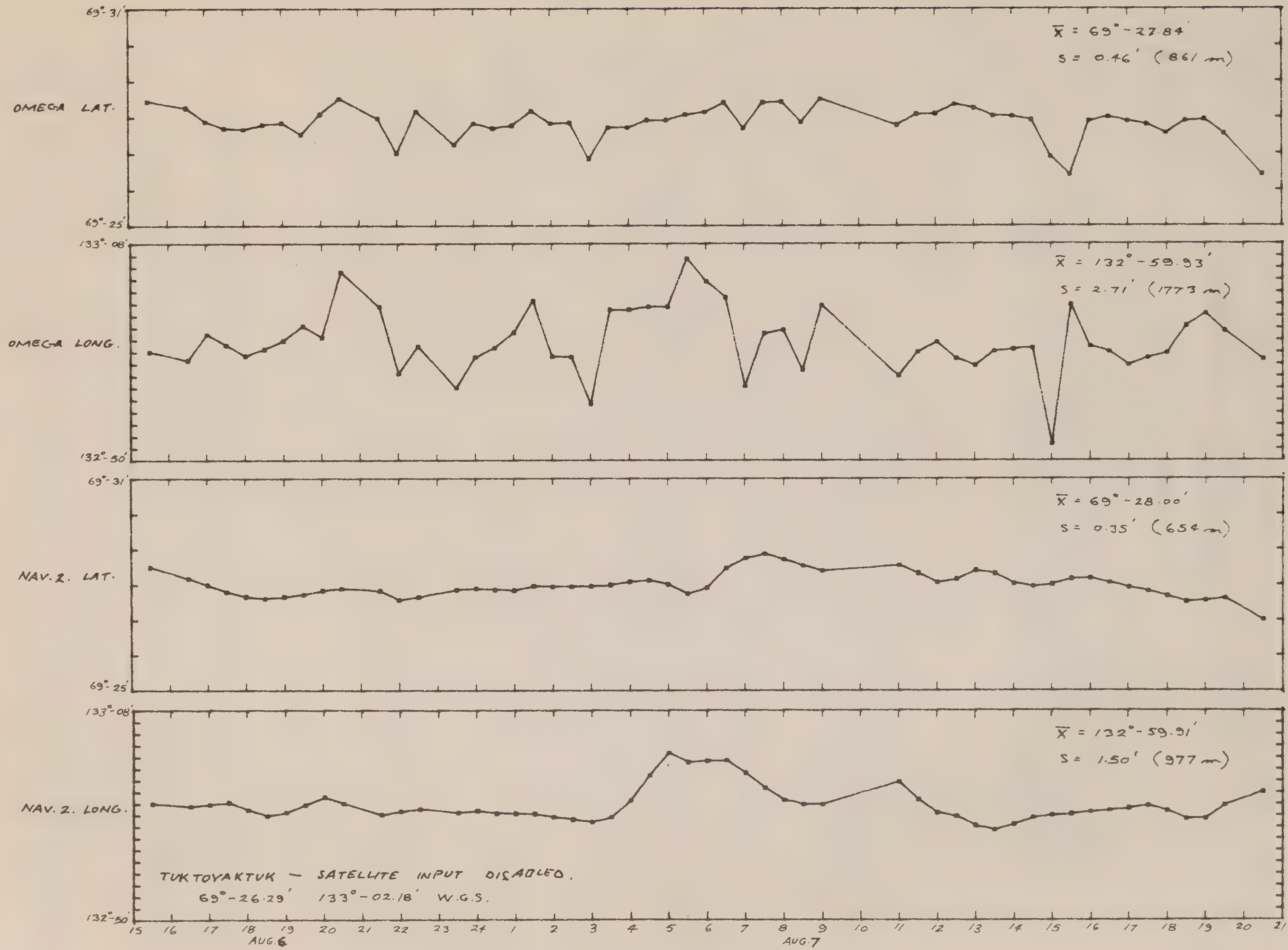

OMEGA LAT.
69°-31'
69°-25'
$\bar{X}$ = 69°-27.84'
S = 0.46' (861 m)
OMEGA LONG.
133°-08'
132°-50'
$\bar{X}$ = 132°-59.93'
S = 2.71' (1773 m)
NAV. 2. LAT.
69°-31'
69°-25'
$\bar{X}$ = 69°-28.00'
S = 0.35' (654 m)
NAV. 2. LONG.
133°-08'
132°-50'
$\bar{X}$ = 132°-59.91'
S = 1.50' (977 m)
TUKTOYAKTUK — SATELLITE INPUT DISABLED.
69°-26.29' 133°-02.18' W.G.S.
15 16 17 18 19 20 21 22 23 24 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
AUG.6
AUG.7

Figure 31

Table 12

Tuktoyaktuk - Stand-Alone Omega Accuracies
MX1105 Receiver

(metres)

	Lat.	Long.	Radial
Omega			
Offset	2870	1459	3220 (1.7 nm)
St. Dev.	861	1773	1971
Smoothed			
Offset	3166	1472	3491 (1.9 nm)
St. Dev.	654	977	1175

Conclusions

1. Loran-C Reception

The Gulf of Alaska (7960) and Bering Sea (9990) Loran-C chains can be received fairly reliably west of Tuktoyaktuk (Longitude 132°W) in the Beaufort Sea. However, only one transmission, that from Tok (7960 - Master) can be received on groundwave. Skywave signals are available from the other Alaska stations. As two chains are available in the western Beaufort Sea, operators in this area would find it advantageous to use receivers that can track both chains simultaneously.

2. Loran-C Chart Lattices

Two lattice overlays have been prepared for Chart 7650 (scale 1:500,000). The overlay for the Gulf of Alaska (7960) lattice shows skywave correction and combined skywave/groundwave corrections. The combined corrections assume an overland conductivity for the Tok transmission of 0.001 mhos/metre. The overlay for the Berin Sea (9990) lattice shows skywave corrections only. In both cases, skywave corrections were made using the U.S. Defense Mapping Agency method, assuming ionospheric heights of 73 km (day) and 91 km (night).

3. Loran-C Accuracies

The hyperbolic fix geometry for both the chains available in the Beaufort Sea is weak. The instability of the ionosphere, even during the day, produces uncertainties in skywave corrections. Correct cycle identification is also a problem when using skywaves. Therefore, fixes produced by time differences from the Alaska chains (7960 and 9990) are likely to have errors, at the one sigma level, of ±6 km, even during the day.

Using Loran-C in the passive ranging mode, assuming frequent satellite fixes, it should be possible to obtain continuous positioning with errors at

the one sigma level of ±500 m during the fourteen hour long summer day. Position errors have not been estimated for Loran-C fixes produced by time differences, or by ranges, obtained during the night.

4. Relationship of Skywave T.O.A. and E.C.D.

The change in Loran-C skywave transmission T.O.A. due to shift in ionospheric height appears to be reflected by a change in E.C.D. If applications for Loran-C skywave transmissions are found in the Canadian Arctic, it may be possible to use the relationship between E.C.D. and change of T.O.A. to predict more accurately skywave corrections for real-time use.

5. Omega Reception

The availability of Omega signals in the Beaufort Sea appears to follow the predictions given in the literature on Omega reception. However, there do appear to be interruptions to continuous reception that decrease the potential usefulness of this system in the Beaufort Sea. In addition, to sudden ionospheric disturbances and polar cap anomalies, Omega reception may also be effected by local weather conditions.

6. Omega Accuracies

The MX1105 Satnav/Omega receiver produces integrated fixes with errors, at the one sigma level, of less than ±500 m when stationary. There is no statistically detectable change in accuracies between day and night. The stand-alone Omega feature on the MX1105 produced fixes with constant offsets of 3.5 km and random errors of ±2 km. As the MX1105 receiver produces positions from several sources, it appears to overcome many of the problems associated with Omega use in high latitudes and the errors associated with these positions are in the same order as those expected from differential Omega.

7. Beaufort Sea Positioning

As the existence of submarine pingoes adds to the usual hazards of Arctic navigation in the Beaufort Sea, and deep draught shipping traffic is expected to increase, there is a need for a reliable general purpose radio navigation aid in the area. This need could be met by differential Omega, or by a system such as the MX1105, if Omega reception can be proved reliable.

In this regard, a detailed analysis of data from existing Omega monitors in the Canadian Arctic, especially at Inuvik, would be extremely useful.

An Accufix-type Loran-C chain may also meet the need for reliable and accurate navigational coverage of the Beaufort Sea. Such a Loran-C type system would also meet some resource exploration company and government survey requirements. However, to use a Loran-C system efficiently, several unknown parameters, such as conductivities over permafrost, conductivities over mixtures of ice and brackish water, transmitted power required for reliable signal tracking and cycle identification, and seasonal variations in these parameters, should be defined by further field work.

References

1. Huggett, W.S. and A.R. Mortimer, 1971. *Observations obtained on a Magnavox Satellite Navigation Receiver in High Latitudes.* Pacific Marine Science Report 71-4, Unpublished Manuscript, Marine Sciences Directorate, Pacific Region, Victoria, B.C. pp. 2-7.

2. Davies, Kenneth, 1965. *Ionospheric Radio Propagation.* National Bureau of Standards Monograph 80, National Bureau of Standards, United States Department of Commerce, Washington, D.C., pp. 393-441.

3. Belrose, J.S., 1958. *Some investigations of the lowest ionosphere.* Ph.D. Thesis, Cambridge University. p.27.

4. Doherty, Robert H., 1967. *Oblique Incidence Ionospheric Reflections of 100 Khz Pulses.* Radio Science, Vol. 2 (new Series), No.6, June 1967. pp. 645-651.

5. Larsen, T.R. and E.V. Thrane, 1976. *Ionospheric Effects on Loran-C in Polar Regions.* AGARD-CP-209, Propagation Limitations of Navigation Positioning Systems Conference Proceedings, Instanbul. pp. 14-1 - 14-8.

6. Livingstone, D.B. and R.K.H. Falconer. 1980. *Skywave Loran-C Navigation at Sea in the Eastern Arctic.* Paper presented at the 19th Annual Canadian Hydrographic Conference, Halifax, In press.

7. Vass, E.R., 1978. *Omega Navigation System: Present Status and Plans 1977-1980.* Navigation, Vol. 25, No.1, Spring 1978, Washington, D.C., pp. 40-48.

Appendix 1

Detailed Position Data from the MX1105

Satnav/Omega Receiver

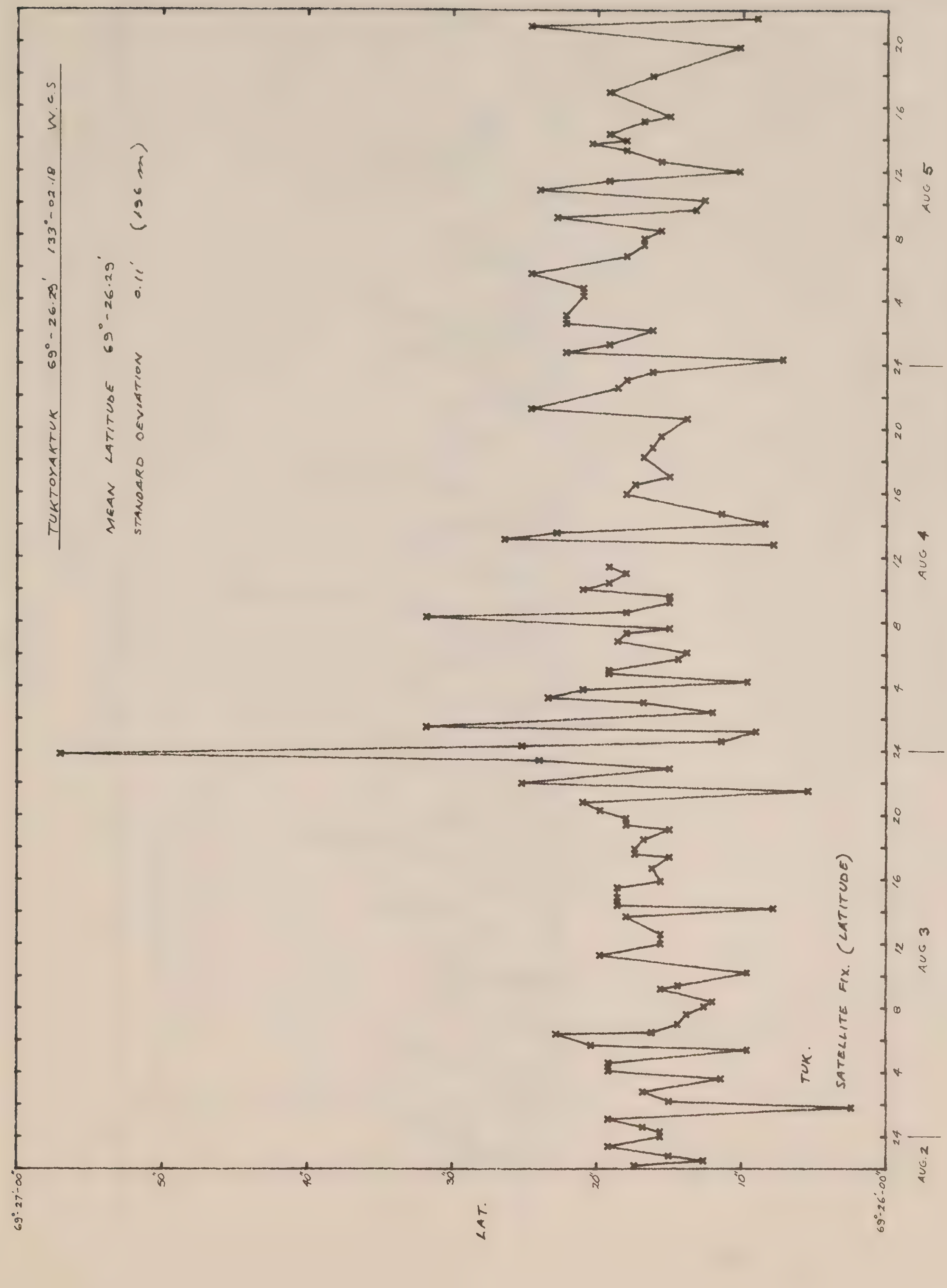

TUKTOYAKTUK 69°-26.29' 133°-02.18 W.C.S
MEAN LATITUDE 69°-26.29'
STANDARD DEVIATION 0.11' (196 m)
TUK.
SATELLITE FIX. (LATITUDE)
LAT.
69°27'00"
50"
40"
30"
20"
10"
69°26'00"
AUG. 2
AUG 3
AUG 4
AUG 5

Figure 1

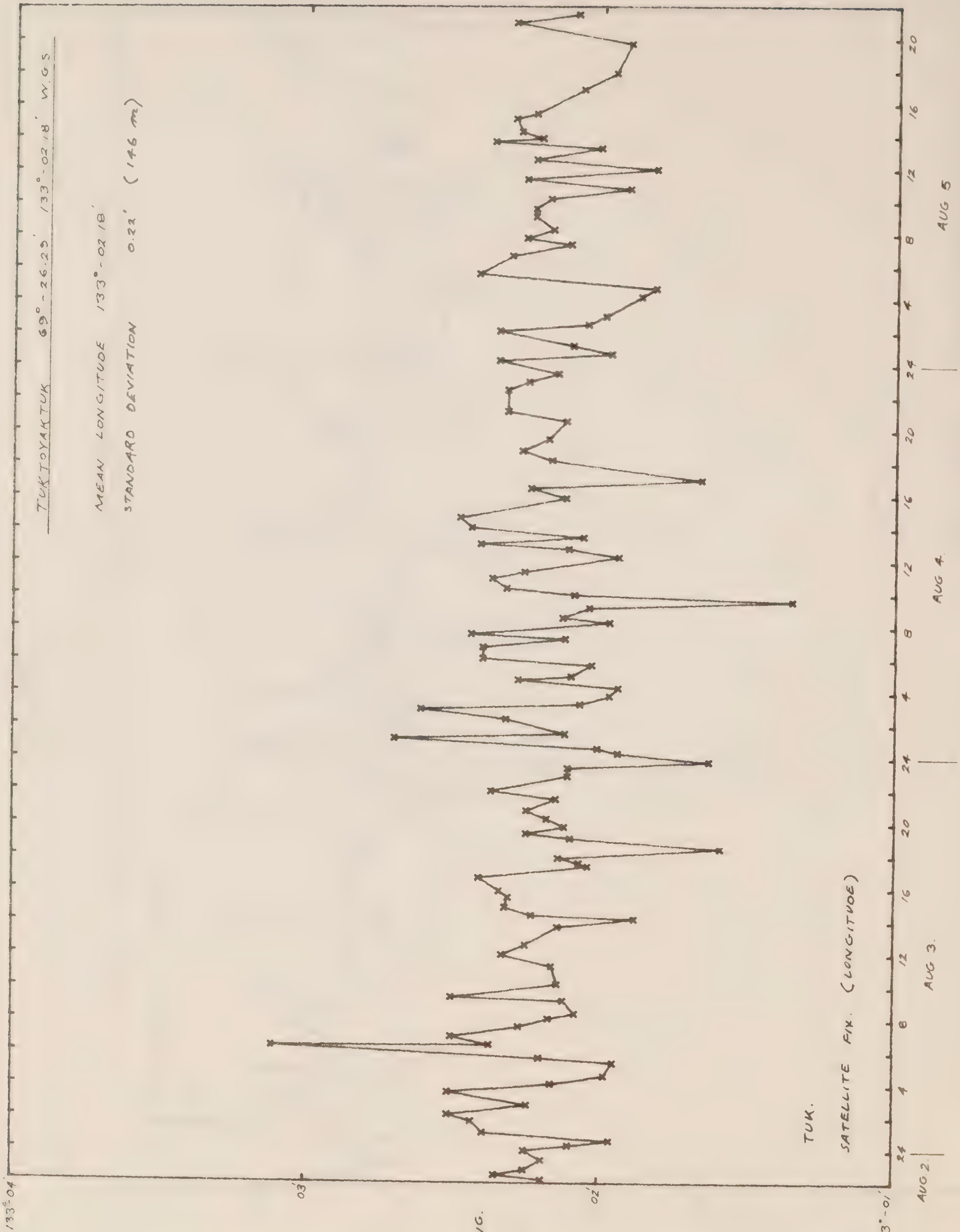

TUKTOYAKTUK 69° - 26.25' 133° - 02.18' W.G.S.
MEAN LONGITUDE 133° - 02.18'
STANDARD DEVIATION 0.22' (146 m)
TUK.
SATELLITE FIX. (LONGITUDE)
LONG.
133°-04'
03'
02'
133°-01'
AUG 2.
AUG 3.
AUG 4.
AUG 5

Figure 2


TUKTOYAKTUK 69°-26.29' 133°-02.18' W.G.S
MEAN LATITUDE 69°-26.36'
STANDARD DEVIATION 0.30' (556 m)
IF THIS POINT OMITTED
X̄ = 69°-26.34'
S = 0.18' (330 m)
TUK.
NAV. 2 POSITION (LATITUDE)
LAT.
69°-30
29'
28'
27'
26'
25'
69°-24'
AUG. 2
AUG. 3
AUG. 4
AUG. 5

Figure 3

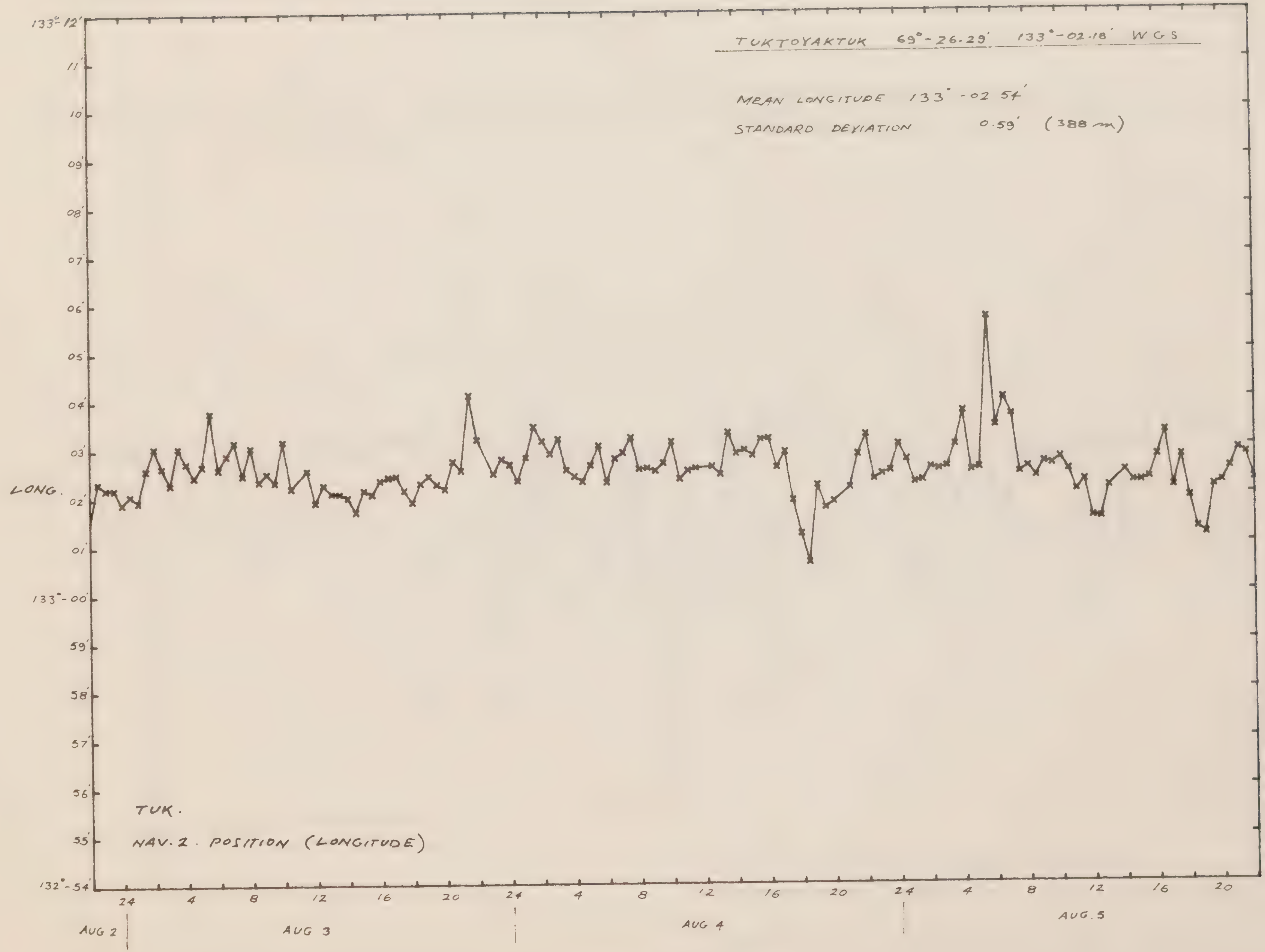

TUKTOYAKTUK 69°-26.29' 133°-02.18' WGS
MEAN LONGITUDE 133°-02 54'
STANDARD DEVIATION 0.59' (388 m)
TUK.
NAV. 2. POSITION (LONGITUDE)
LONG.
133°-12'
11'
10'
09'
08'
07'
06'
05'
04'
03'
02'
01'
133°-00'
59'
58'
57'
56'
55'
132°-54'
24
4
8
12
16
20
AUG 2
AUG 3
AUG 4
AUG. 5

Figure 4

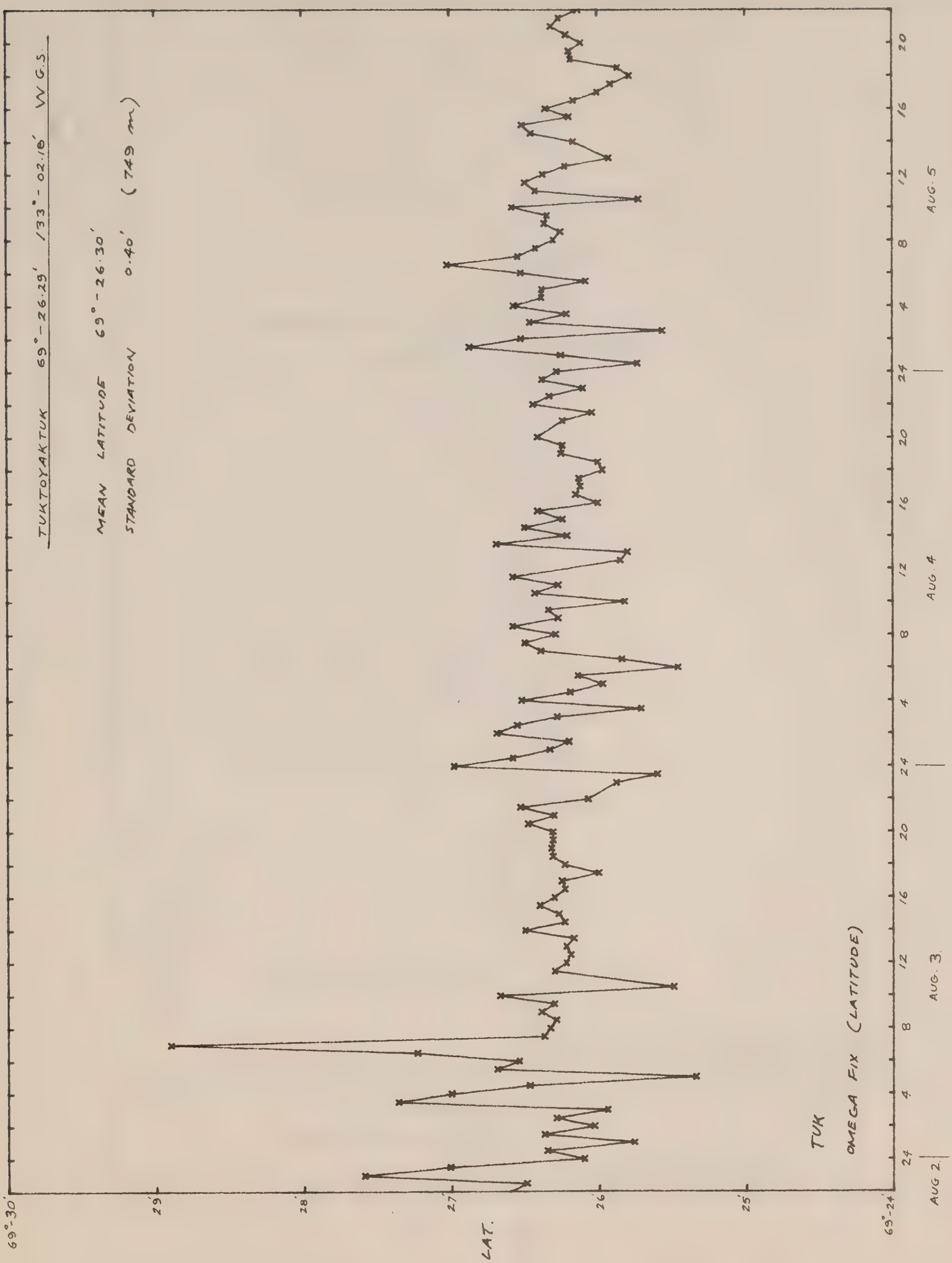

TUKTOYAKTUK 69°-26.29' /133°-02.18' W.G.S.
MEAN LATITUDE 69°-26.30'
STANDARD DEVIATION 0.40' (749 m)
TUK
OMEGA FIX (LATITUDE)
LAT.
69°-30'
29'
28'
27'
26'
25'
69°-24'
24
4
8
12
16
20
AUG 2.
AUG. 3.
AUG. 4
AUG. 5

Figure 5

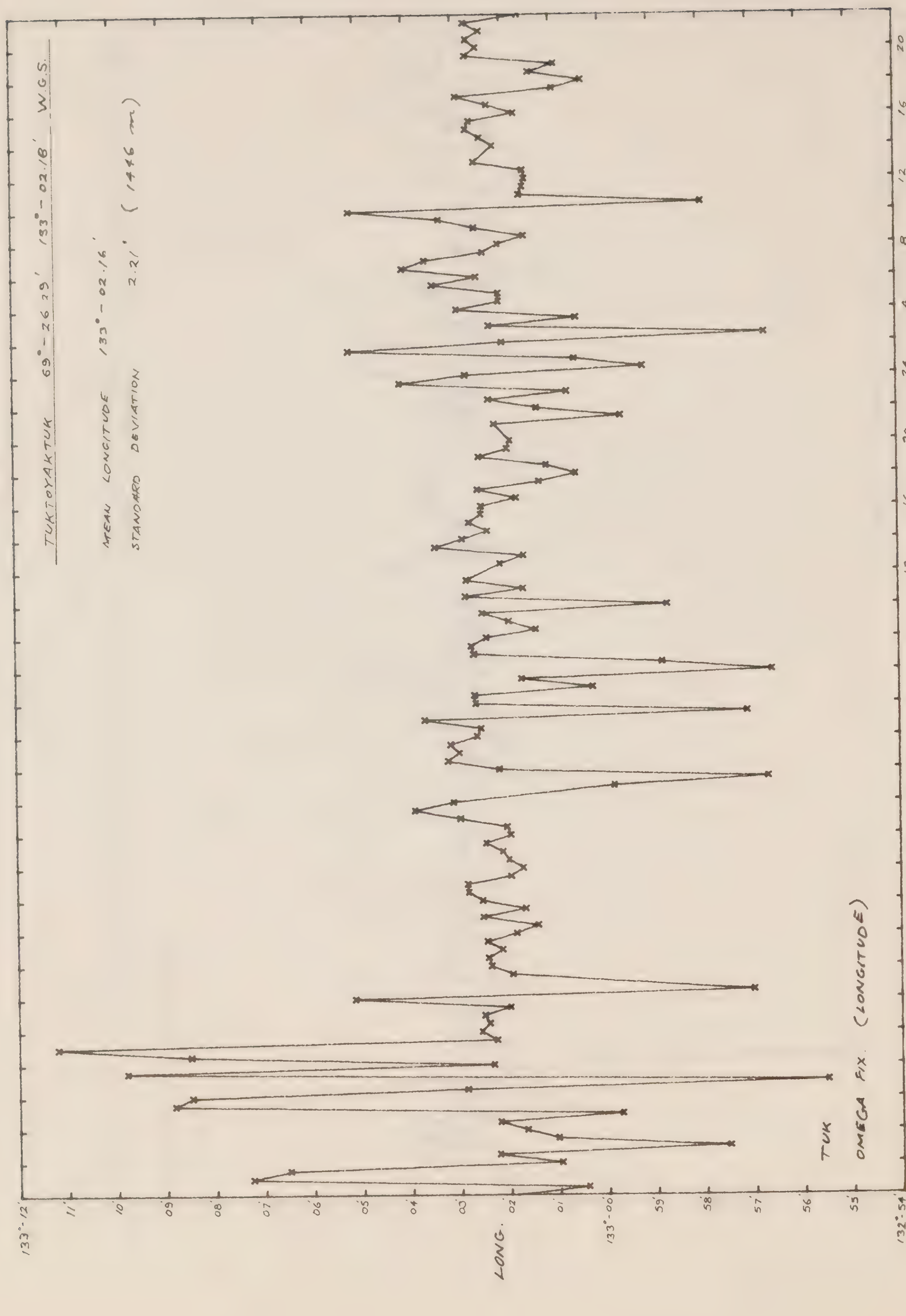

TUKTOYAKTUK 69°-26.29' 133°-02.18' W.G.S.
MEAN LONGITUDE 133°-02.16'
STANDARD DEVIATION 2.21' (1446 m)
TUK
OMEGA FIX (LONGITUDE)
LONG.
133°-12
11
10
09
08
07
06
05
04
03
02
01
133°-00
59
58
57
56
55
132°-54
AUG 2
AUG 3
AUG 4
AUG 5

Figure 6


TUKTOYAKTUK 69°-26.29' 133°-02.18' W.G.S
MEAN LATITUDE 69°-26.43'
STANDARD DEVIATION 0.43' (803 m)
IF THIS POINT OMITTED
x̄ = 69°-26.37'
S = 0.13' (245 m)
TUK.
NAV.2 POSITION (LATITUDE)
AUG. 3.
LAT.
69°30'
29'
28'
27'
26'
25'
69°24'
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

Figure 7

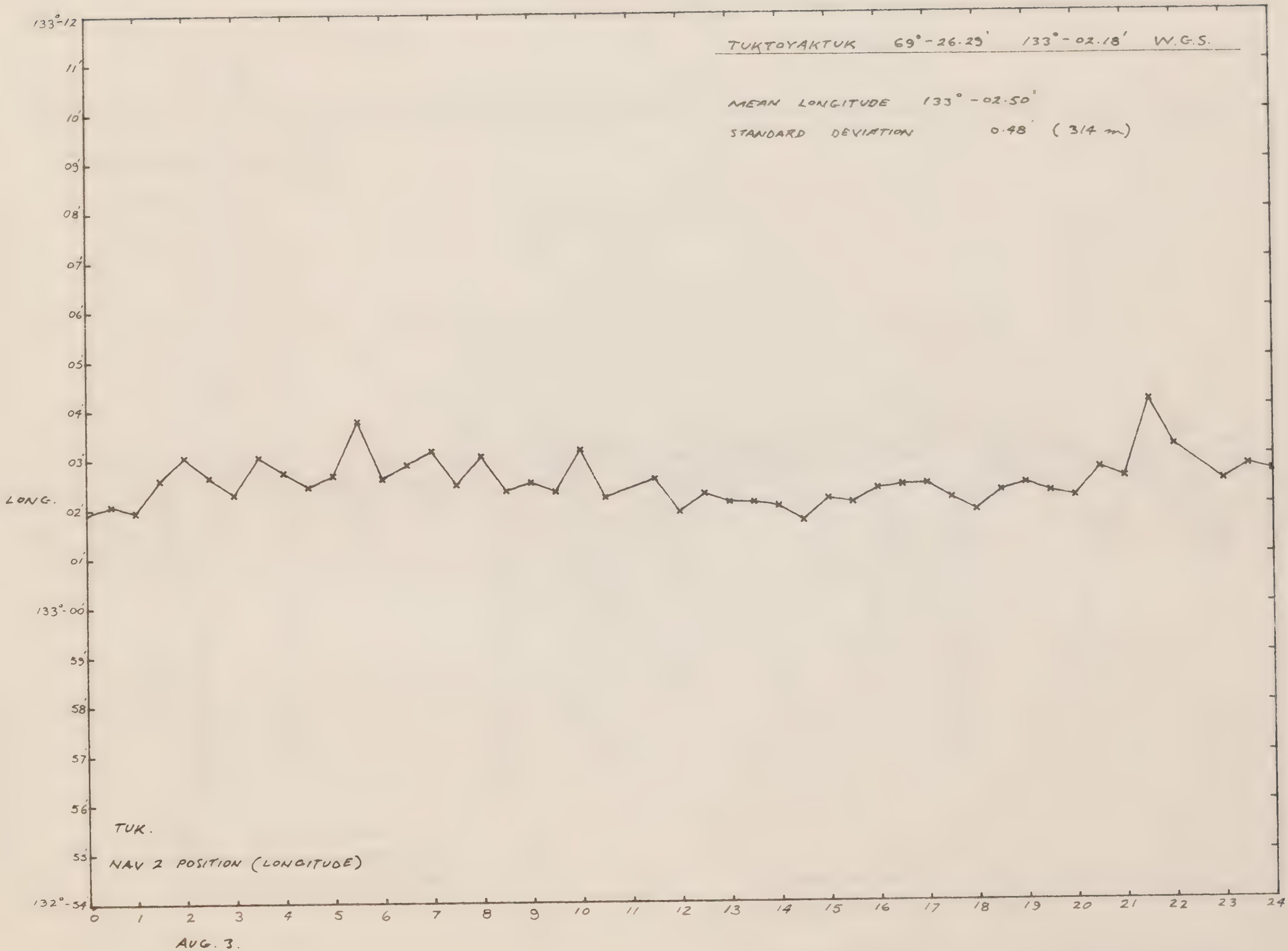

TUKTOYAKTUK 69°-26.29' 133°-02.18' W.G.S.
MEAN LONGITUDE 133°-02.50'
STANDARD DEVIATION 0.48' (314 m)
LONG.
133°-12
11'
10'
09'
08'
07'
06'
05'
04'
03'
02'
01'
133°-00'
59'
58'
57'
56'
55'
132°-54
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
AUG. 3.
TUK.
NAV 2 POSITION (LONGITUDE)

Figure 8

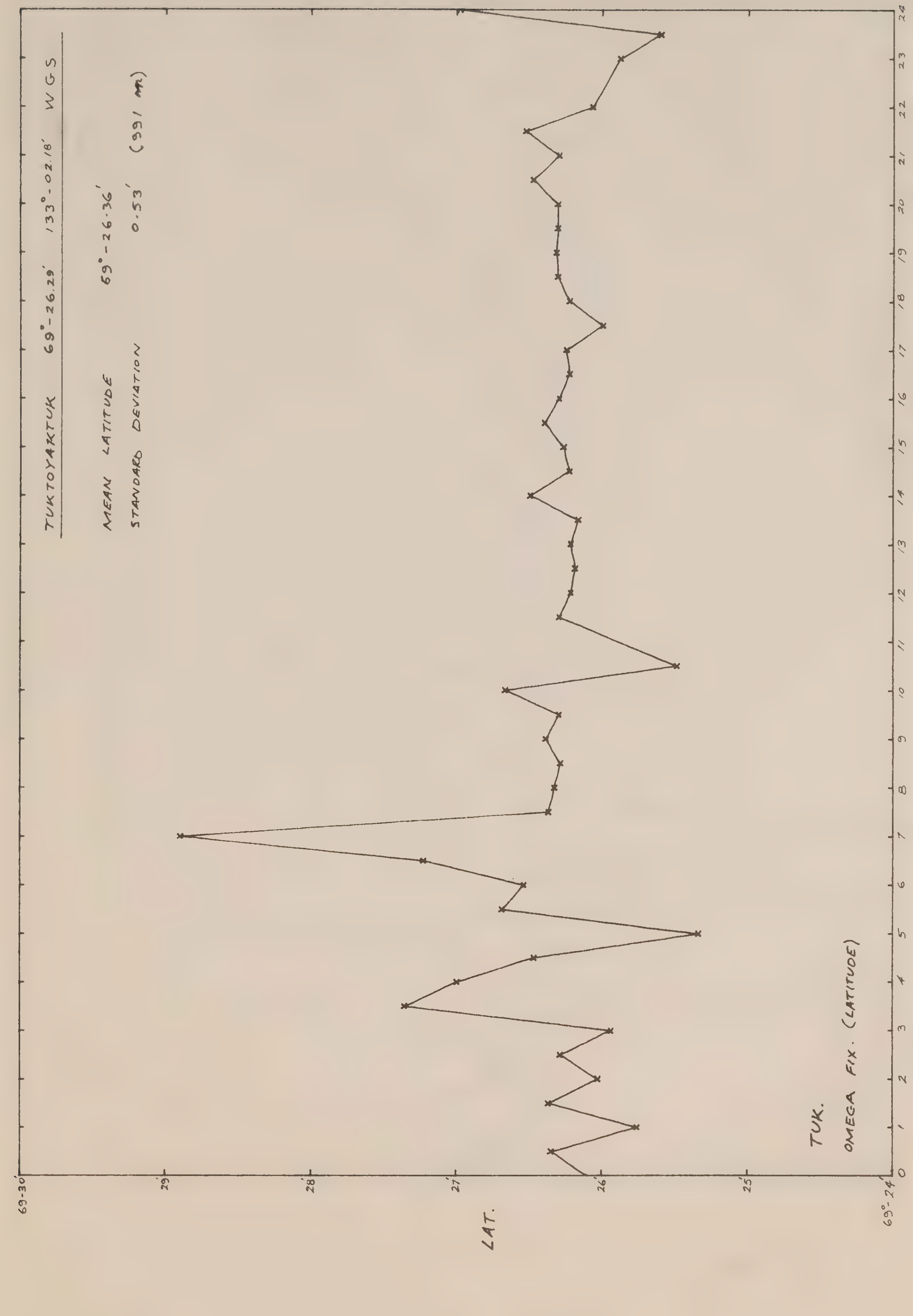

TUKTOYAKTUK 69°-26.29' 133°-02.18' WGS
MEAN LATITUDE 69°-26.36'
STANDARD DEVIATION 0.53' (991 m)
TUK.
OMEGA FIX. (LATITUDE)
AUG. 3
LAT.
69°-30'
29'
28'
27'
26'
25'
69°-24'
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

Figure 9

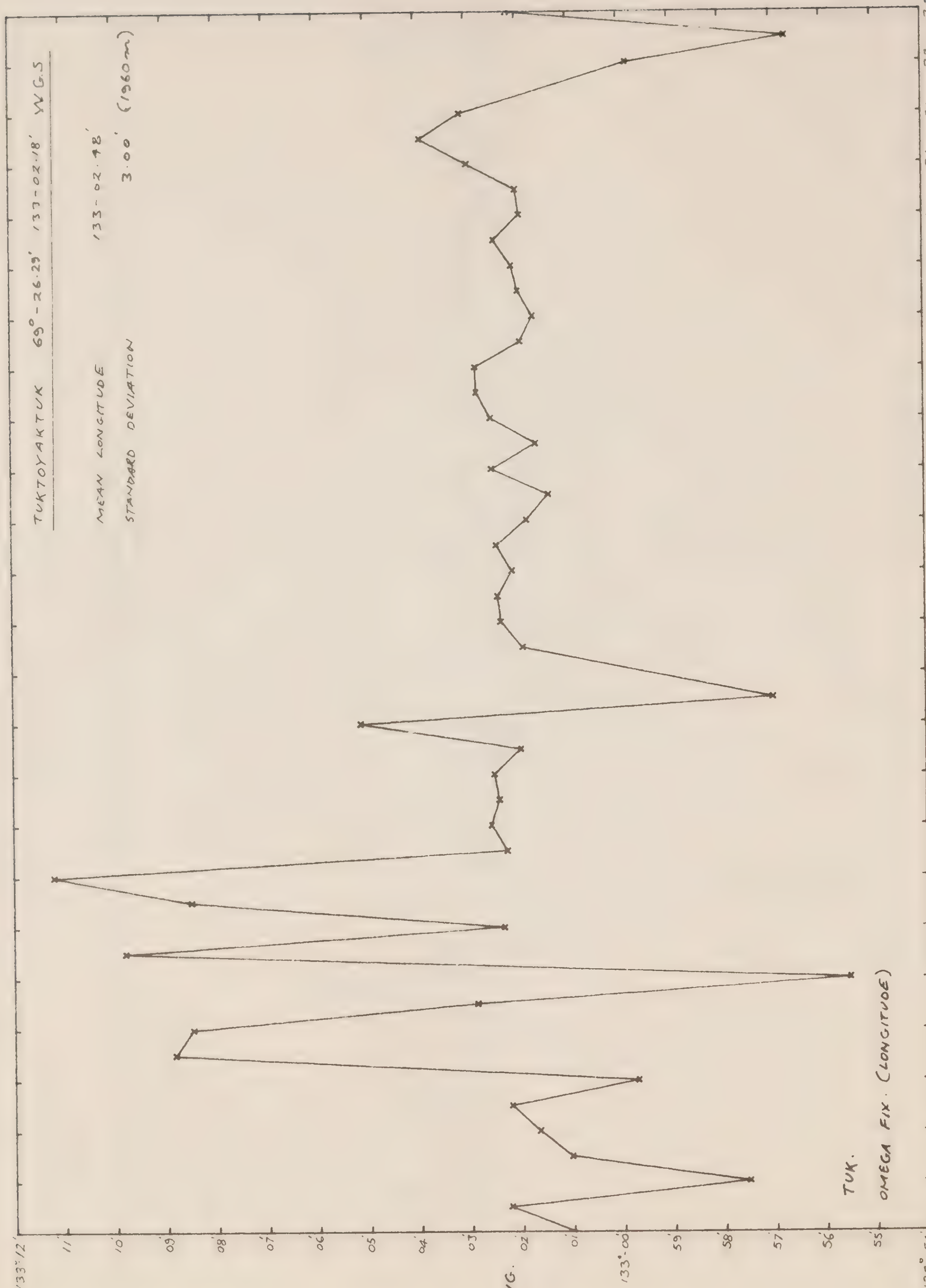

TUKTOYAKTUK 69°-26.29' 133-02.18' W.G.S
MEAN LONGITUDE 133-02.48'
STANDARD DEVIATION 3.00' (1960m)
TUK.
OMEGA FIX. (LONGITUDE)
AUG. 3.
LONG.

Figure 10


TUKTOYAKTUK 69°-26.29' 133°-02.18' W.G.S.
MEAN LATITUDE 69°-26.34'
STANDARD DEVIATION 0.19' (346 m)
TUK.
NAV.2 POSITION (LATITUDE)
AUG. 4.
LAT.
69°-30'
29'
28'
27'
26'
25'
69°-24'
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
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19
20
21
22
23
24

Figure 11

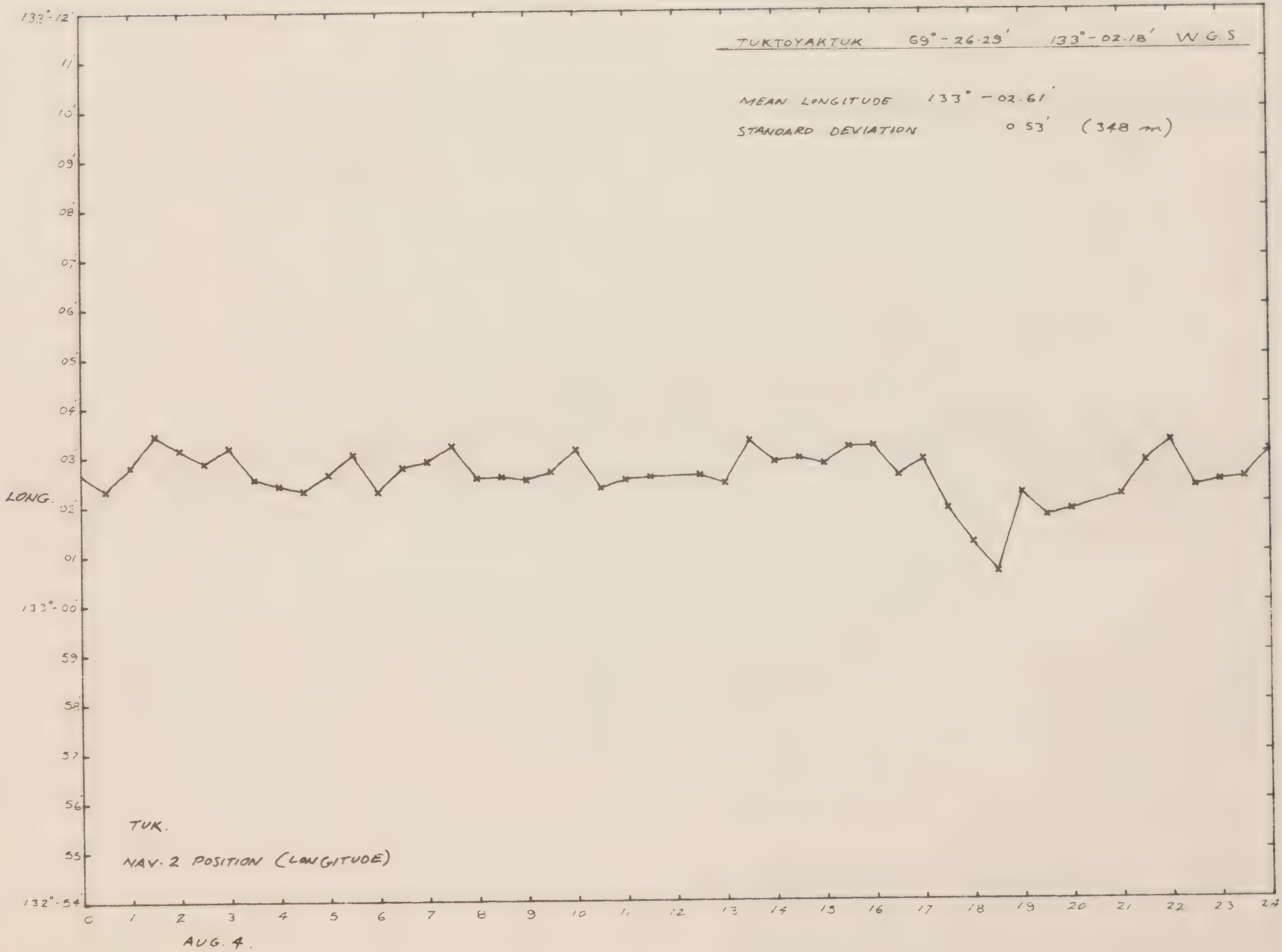

TUKTOYAKTUK 69°-26.29' 133°-02.18' W.G.S
MEAN LONGITUDE 133° -02.61'
STANDARD DEVIATION 0.53' (348 m)
LONG.
133°-12'
11'
10'
09'
08'
07'
06'
05'
04'
03'
02'
01'
133°-00'
59
58
57
56
55
132°-54'
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
AUG. 4.
TUK.
NAV. 2 POSITION (LONGITUDE)

Figure 12

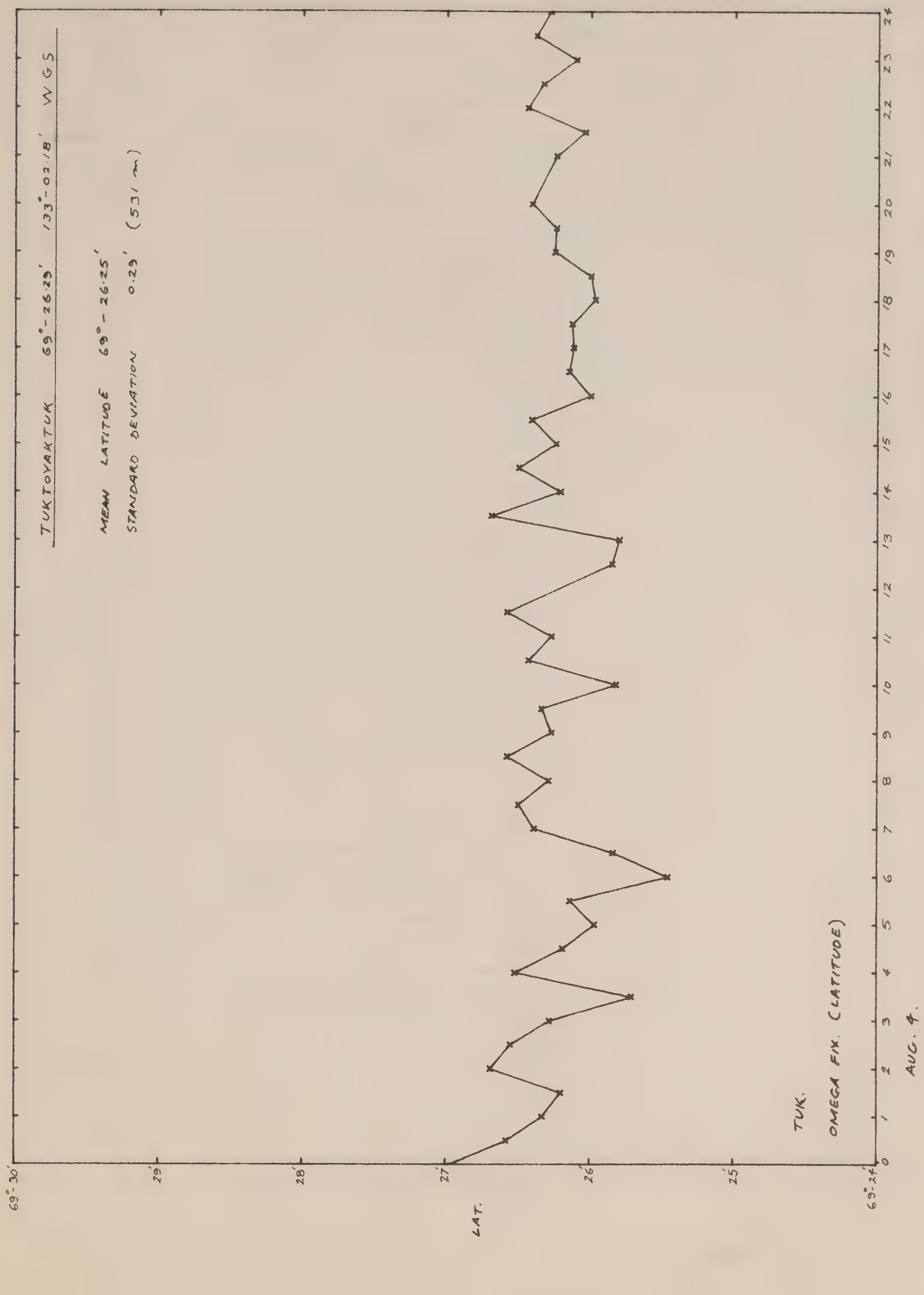

TUKTOYAKTUK 69°-26.29' 133°-02.18' WGS
MEAN LATITUDE 69°-26.25'
STANDARD DEVIATION 0.29' (531 m)
TUK.
OMEGA FIX. (LATITUDE)
AUG. 4.
LAT.
69°-30'
29'
28'
27'
26'
25'
69°-24'
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Figure 13

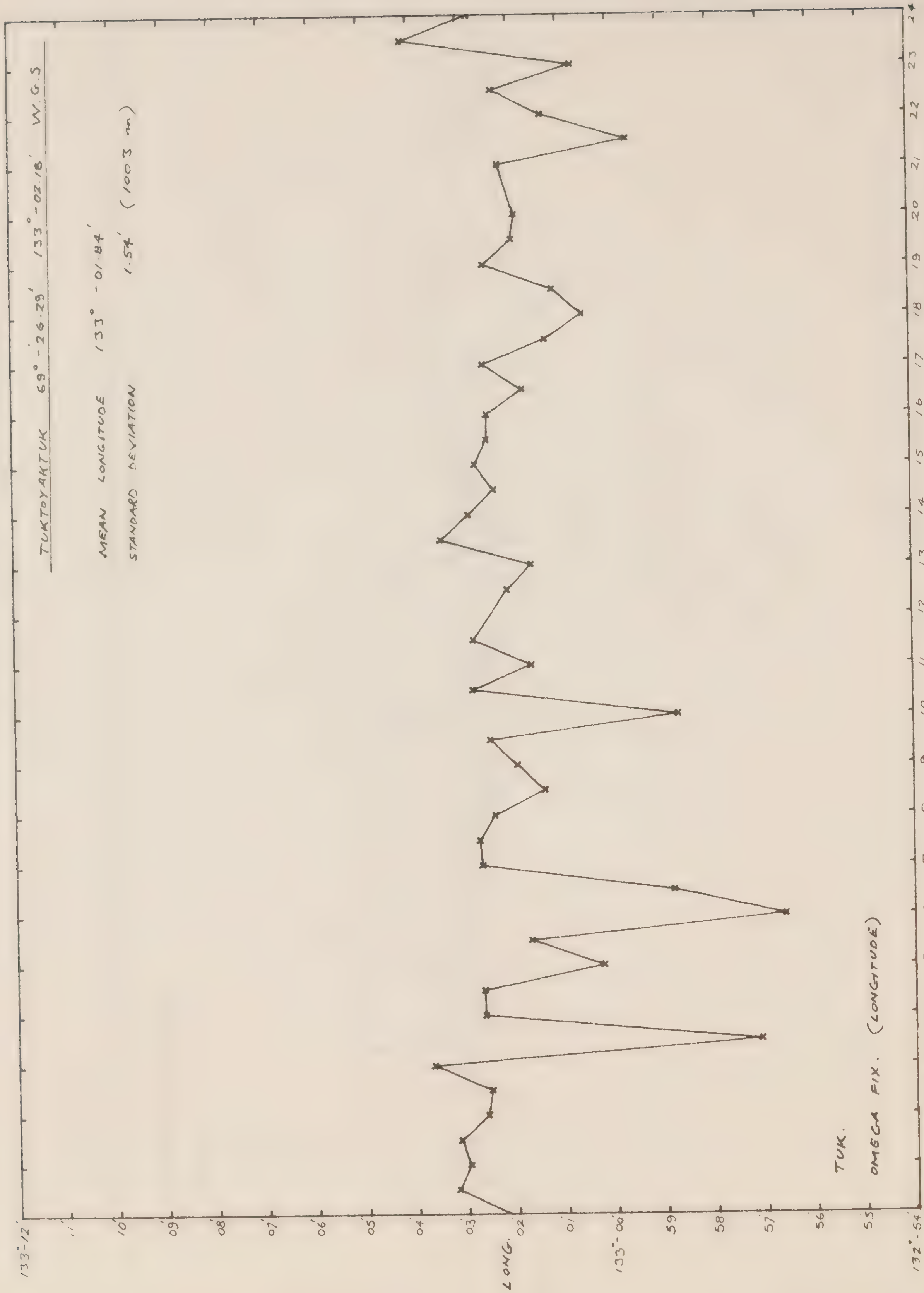
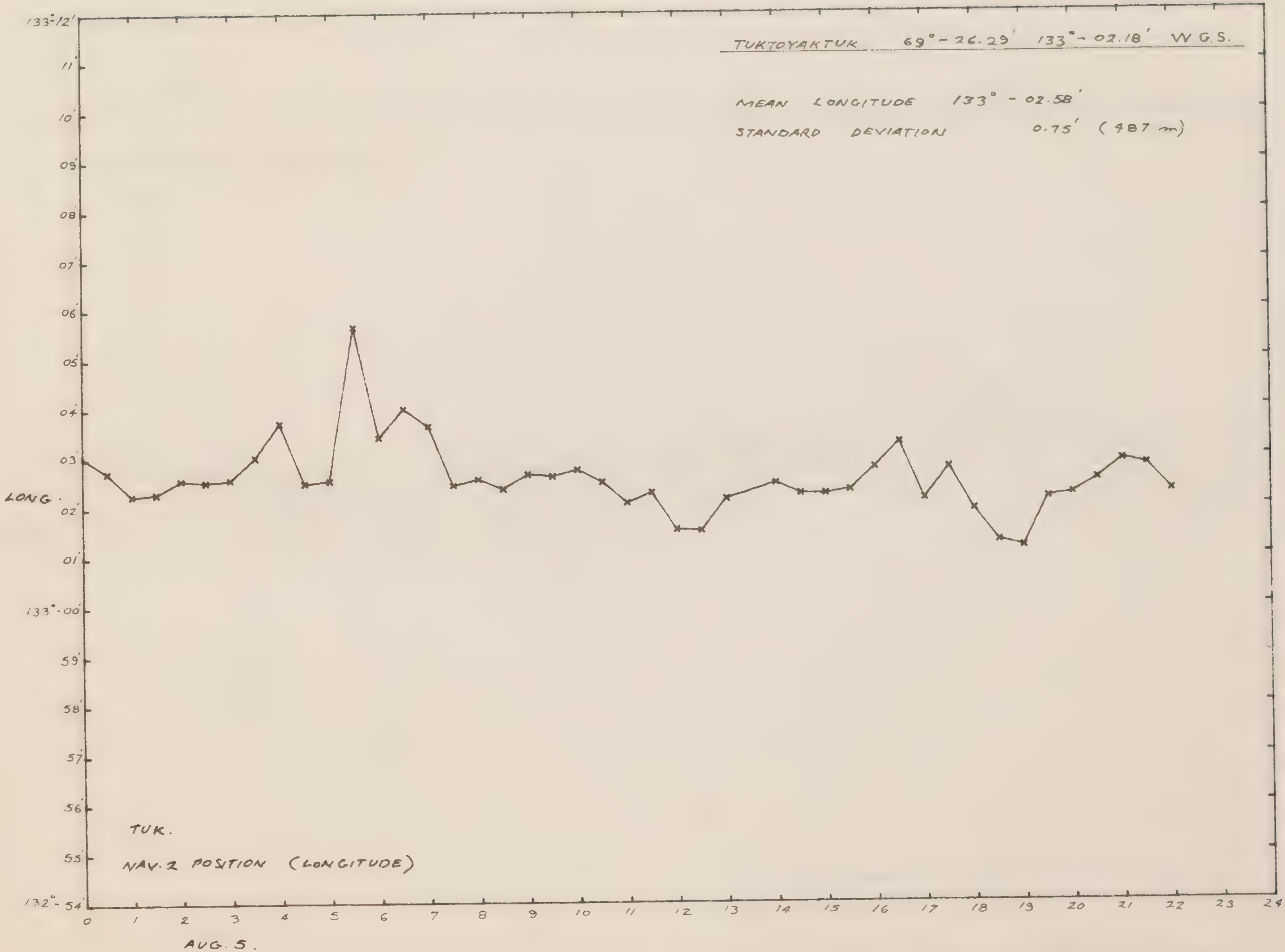

TUKTOYAKTUK 69°-26.29' 133°-02.18' W.G.S
MEAN LONGITUDE 133° -01.84'
STANDARD DEVIATION 1.54' (1003 m)
TUK.
OMEGA FIX. (LONGITUDE)
AUG. 4.
LONG.
133°-12'
11
10
09
08
07
06
05
04
03
02
01
133°-00'
59
58
57
56
55
132°-54'
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

Figure 14


TUKTOYAKTUK 69° - 26.29' 133° - 02.18' W.G.S.
MEAN LATITUDE 69° - 26.32'
STANDARD DEVIATION 0.22' (413 m)
TUK.
NAV. 2 POSITION (LATITUDE)
AUG. 5.
LAT.
69°30'
29'
28'
27'
26'
25'
69°24'
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Figure 15


TUKTOYAKTUK 69° - 26.29' 133° - 02.18' W.G.S.
MEAN LONGITUDE 133° - 02.58'
STANDARD DEVIATION 0.75' (487 m)
TUK.
NAV. 2 POSITION (LONGITUDE)
AUG. 5.
LONG.
133°-12'
11'
10'
09'
08'
07'
06'
05'
04'
03'
02'
01'
133°-00'
59'
58'
57'
56'
55'
132°-54'
0
1
2
3
4
5
6
7
8
9
10
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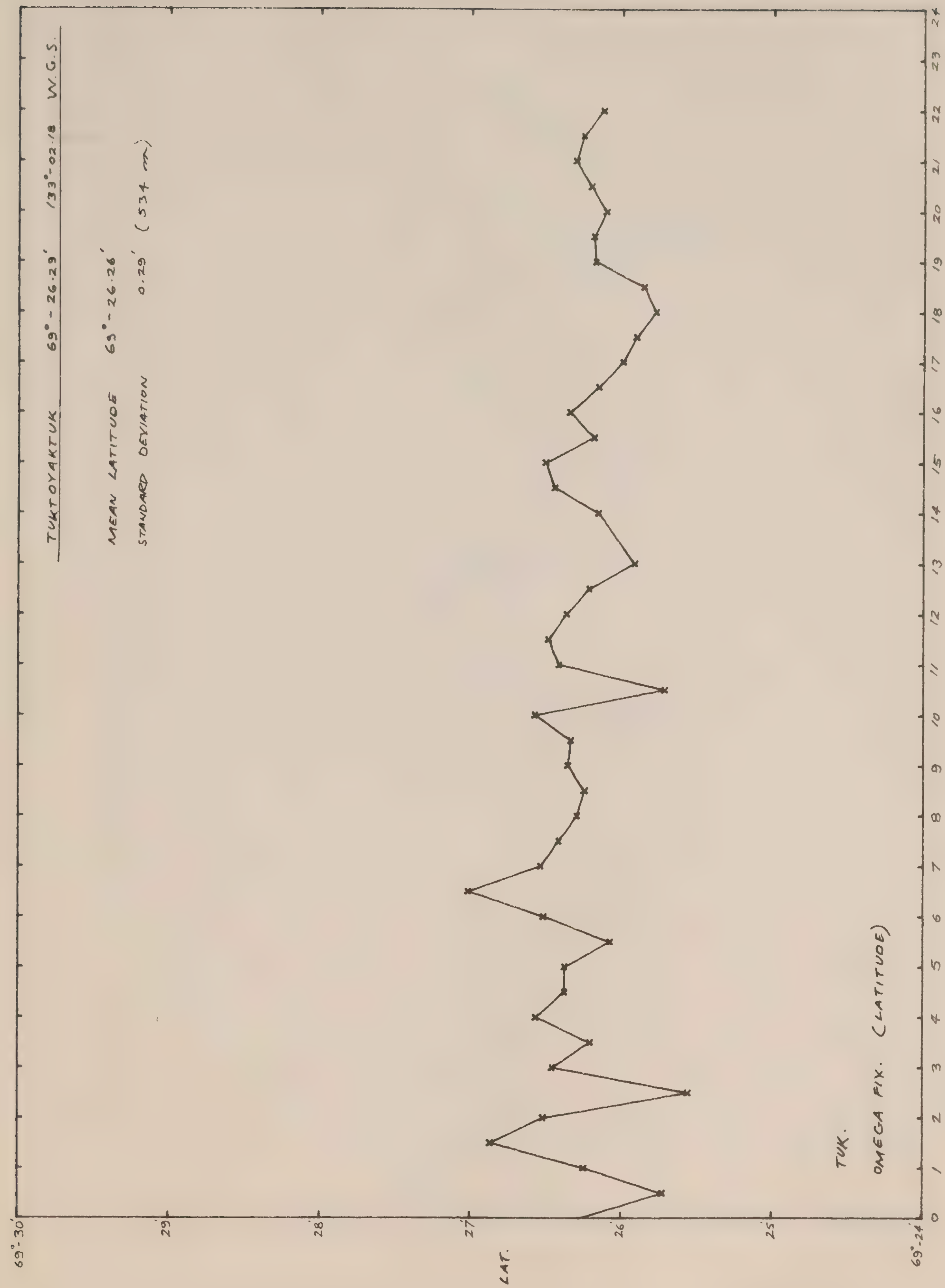
23
24

Figure 16


TUKTOYAKTUK 69° - 26.29' 133°-02.18 W.G.S.
MEAN LATITUDE 69° - 26.26'
STANDARD DEVIATION 0.29' (534 m)
TUK.
OMEGA FIX. (LATITUDE)
AUG. 5.
LAT.
69°-30'
29'
28'
27'
26'
25'
69°-24'
0
1
2
3
4
5
6
7
8
9
10
11
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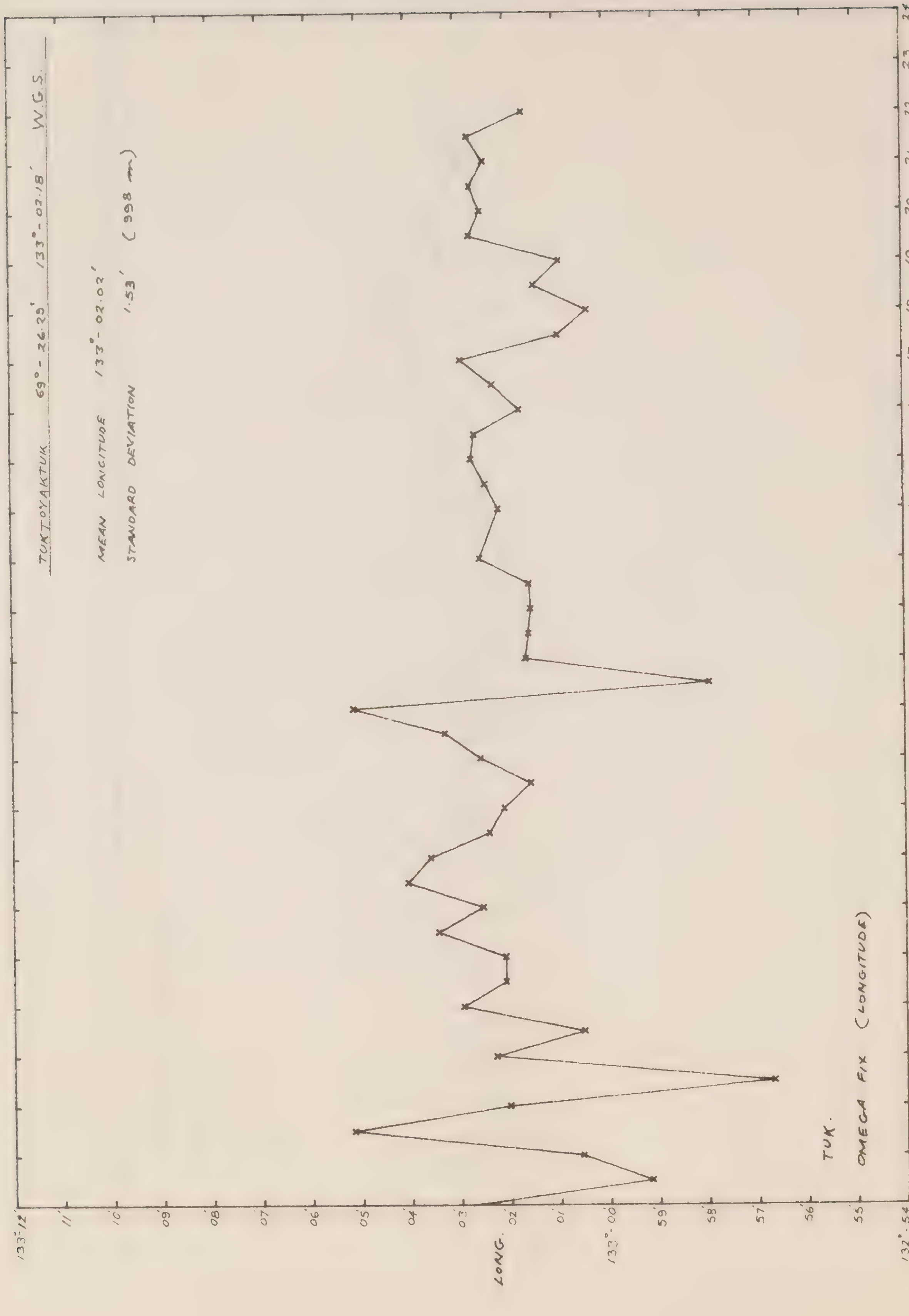
23
24

Figure 17


TUKTOYAKTUK 69° - 26.25' 133° - 02.18' W.G.S.
MEAN LONGITUDE 133° - 02.02'
STANDARD DEVIATION 1.53' (998 m)
TUK.
OMEGA FIX (LONGITUDE)
AUG. 5
LONG.
133°·12
11
10
09
08
07
06
05
04
03
02
01
133°-00
59
58
57
56
55
132°·54
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
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16
17
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23
24

Figure 18

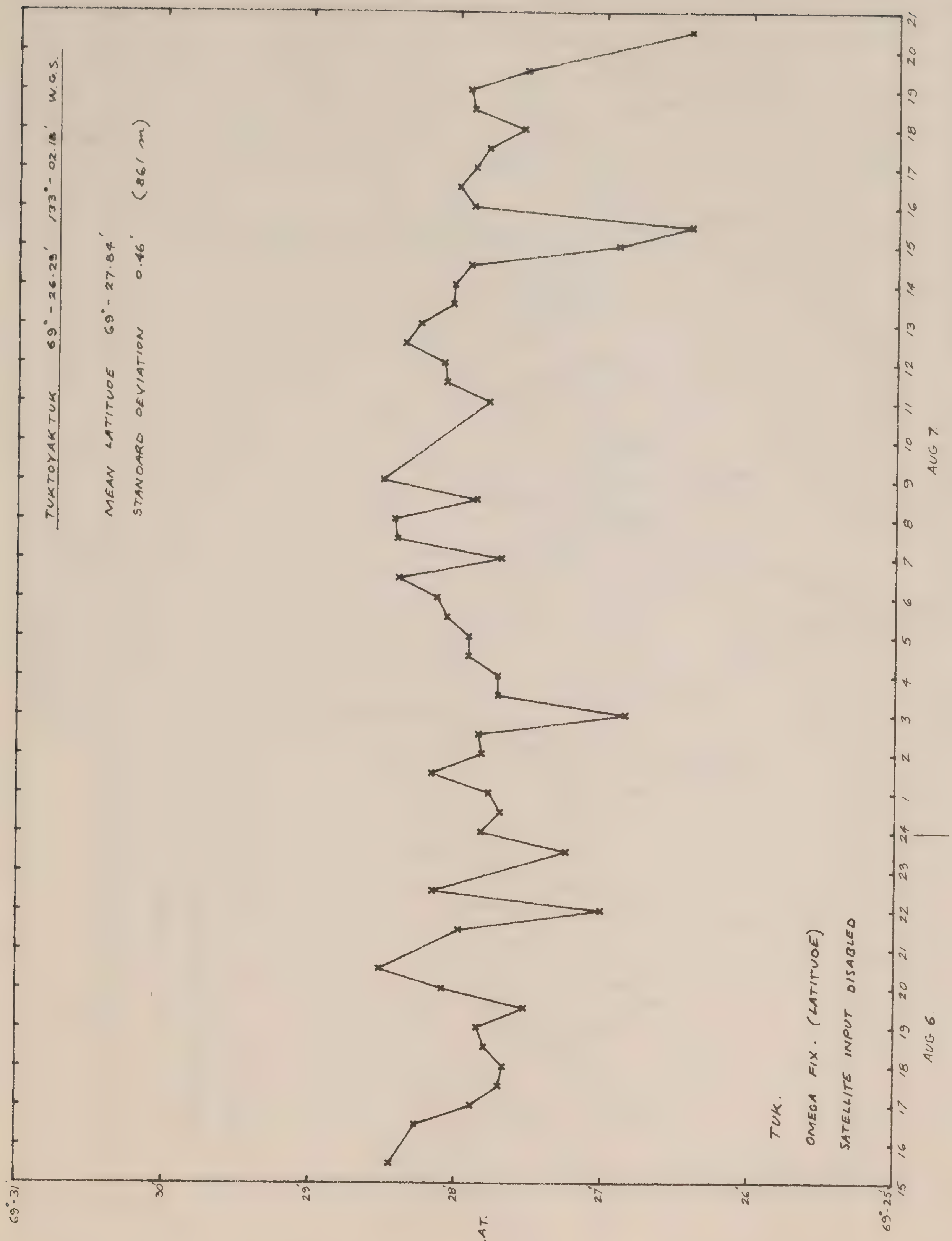
TUKTOYAKTUK 69° - 26.29' 133° - 02.18' W.G.S.
MEAN LATITUDE 69° - 27.84'
STANDARD DEVIATION 0.46' (861 m)
TUK.
OMEGA FIX. (LATITUDE)
SATELLITE INPUT DISABLED
AUG 6.
AUG 7.
LAT.
69°·31'
30'
29'
28'
27'
26'
69°·25'
15 16 17 18 19 20 21 22 23 24 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21

Figure 19

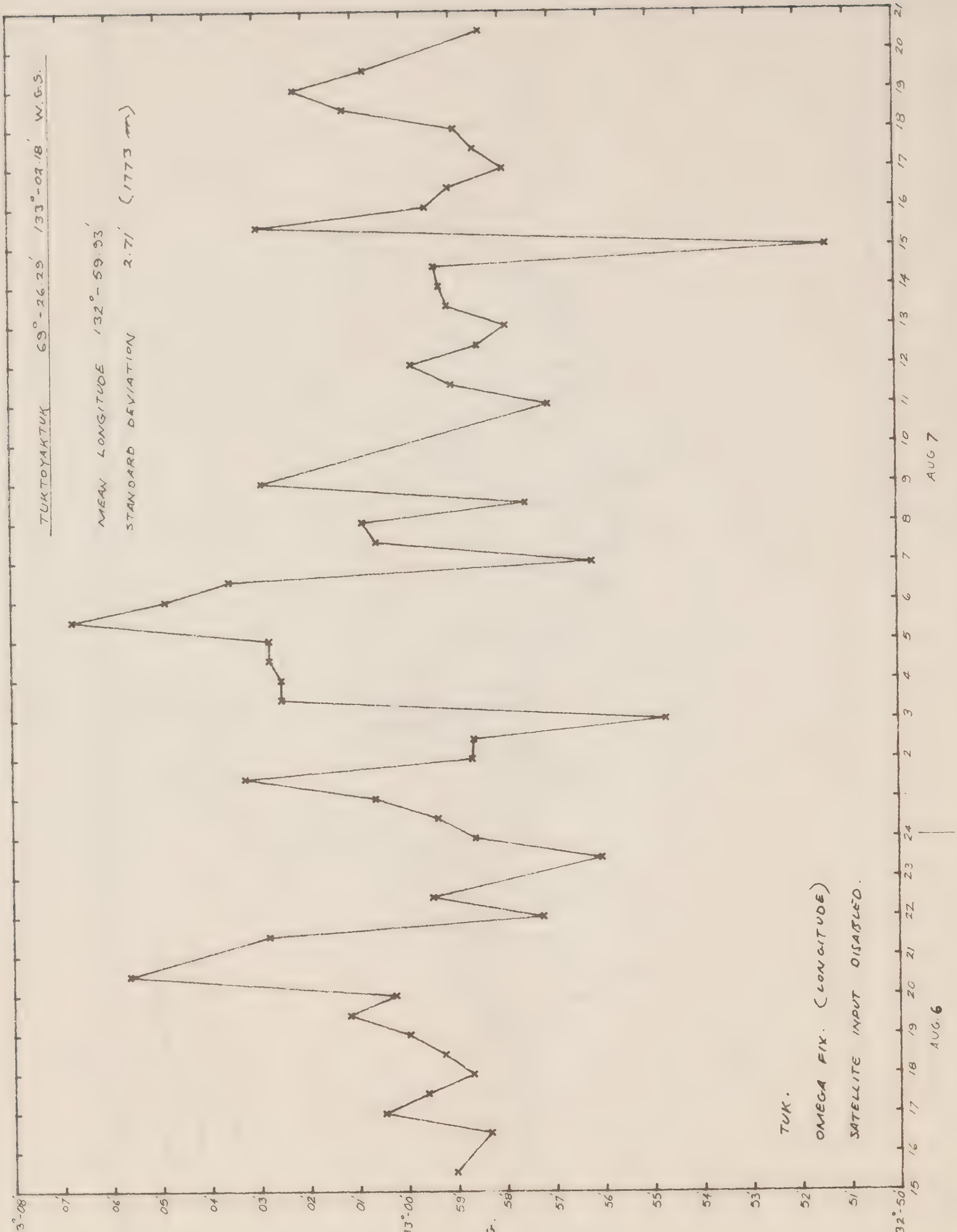
TUKTOYAKTUK 69°-26.29' 133°-07.18' W.G.S.
MEAN LONGITUDE 132°-59.93'
STANDARD DEVIATION 2.71' (1773 m)
TUK.
OMEGA FIX. (LONGITUDE)
SATELLITE INPUT DISABLED.
LONG.
133°-08
07
06
05
04
03
02
01
133°-00
59
58
57
56
55
54
53
52
51
132°-50
15 16 17 18 19 20 21 22 23 24 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
AUG. 6
AUG 7

Figure 20


TUKTOYAKTUK 69°-26.29' 133°-02.18' W G.S
MEAN LATITUDE 69°-28.00'
STANDARD DEVIATION 0.35' (654 m)
TUK.
NAV.2 POSITION (LATITUDE)
SATELLITE INPUT DISABLED
AUG. 6.
AUG. 7.
LAT.
69°-31'
30'
29'
28'
27'
26'
69°-25'

Figure 21

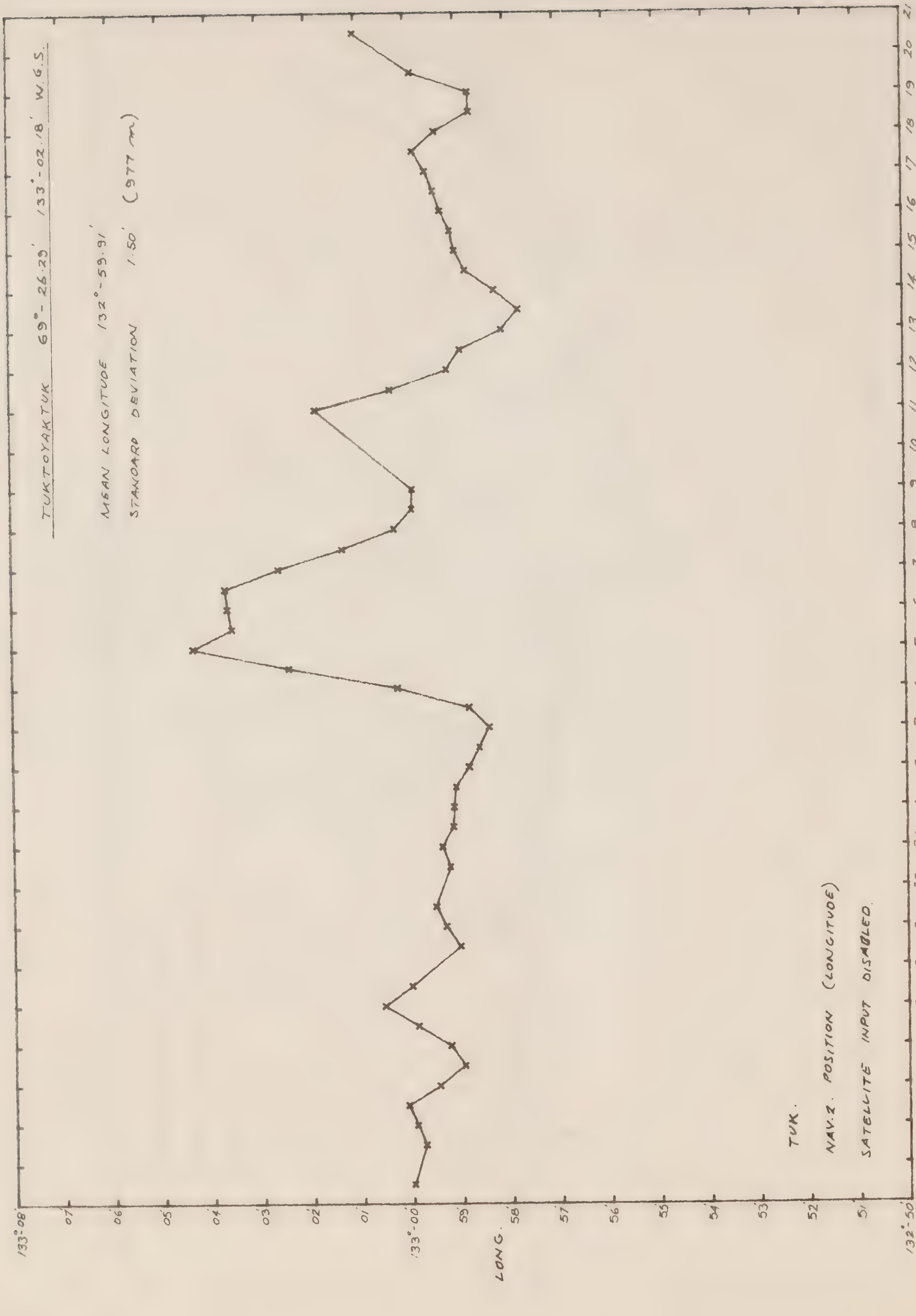
TUKTOYAKTUK 69°-26.29' 133°-02.18' W.G.S.
MEAN LONGITUDE 132°-59.91'
STANDARD DEVIATION 1.50' (977 m)
TUK.
NAV.2. POSITION (LONGITUDE)
SATELLITE INPUT DISABLED.
LONG.
133°08'
07
06
05
04
03
02
01
133°-00
59
58
57
56
55
54
53
52
51
132°-50
15 16 17 18 19 20 21 22 23 24 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
AUG 6
AUG 7

Figure 22

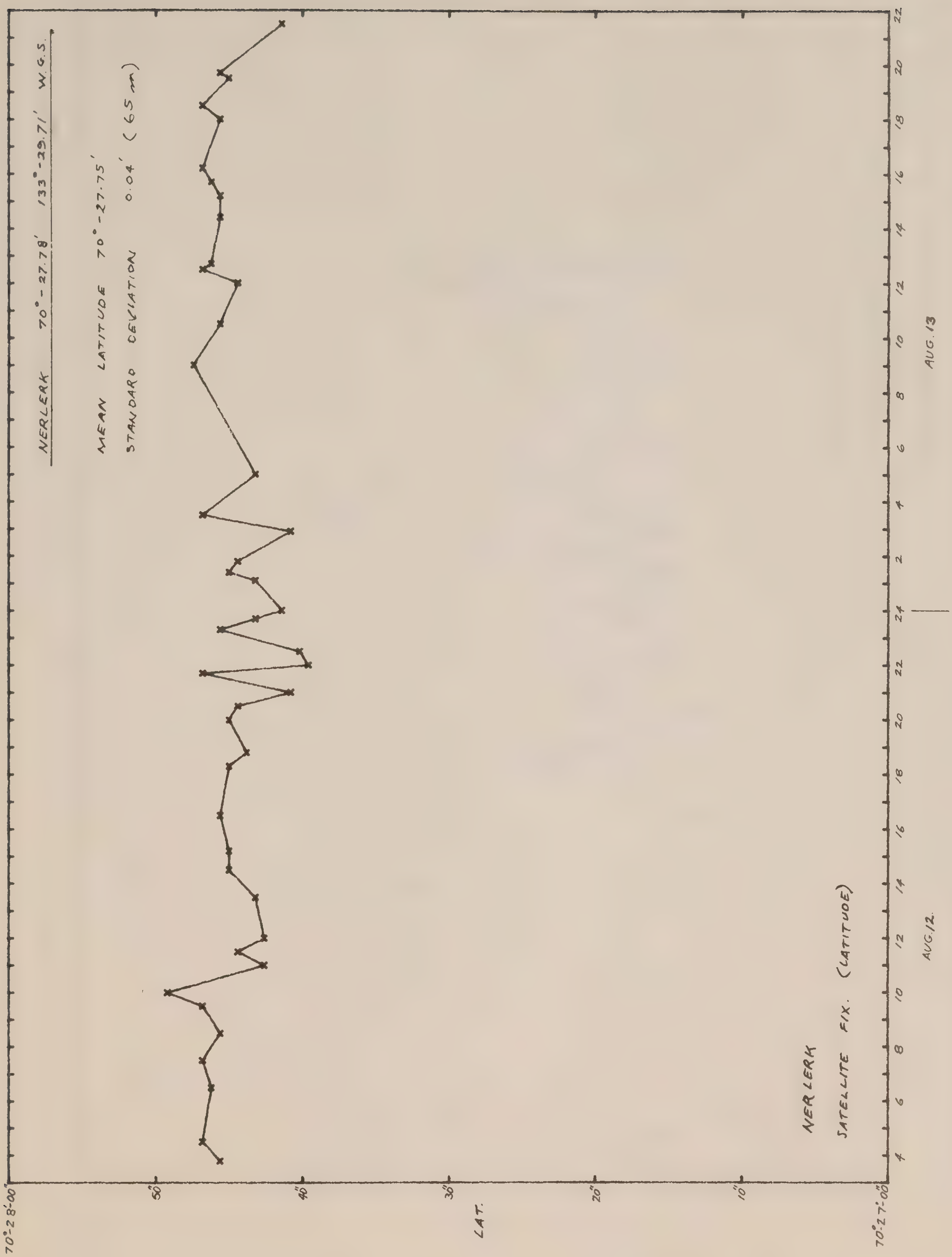
NERLERK 70° - 27.78' 133°-29.71' W.G.S.
MEAN LATITUDE 70°-27.75'
STANDARD DEVIATION 0.04' (65 m)
NERLERK
SATELLITE FIX. (LATITUDE)
AUG.12
AUG.13
LAT.
70°28'00"
70°27'00"

Figure 23

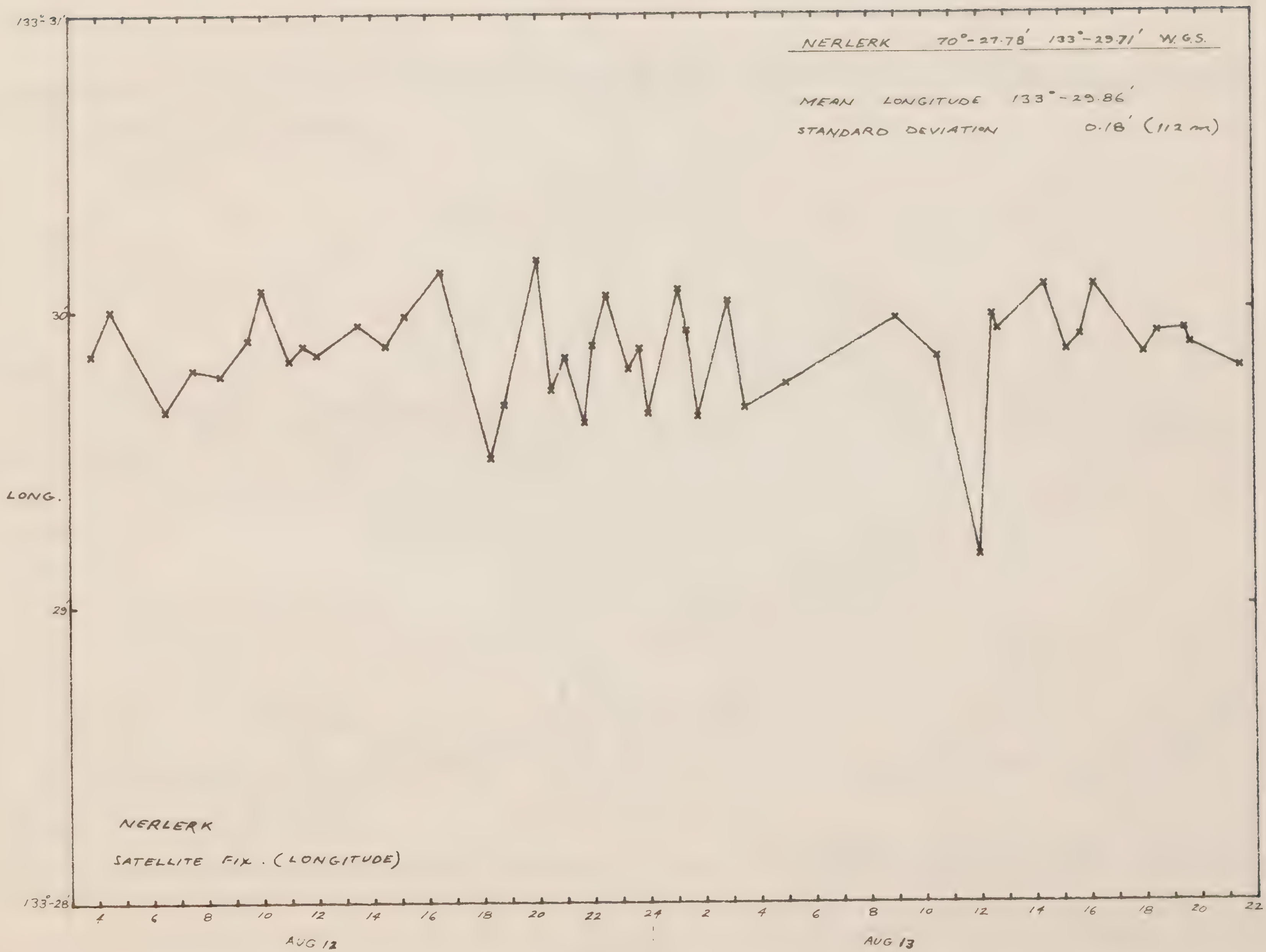
NERLERK 70°-27.78' 133°-29.71' W.G.S.
MEAN LONGITUDE 133°-29.86'
STANDARD DEVIATION 0.18' (112 m)
NERLERK
SATELLITE FIX. (LONGITUDE)
133°-31'
30'
LONG.
29'
133°-28'
4 6 8 10 12 14 16 18 20 22 24 2 4 6 8 10 12 14 16 18 20 22
AUG 12
AUG 13

Figure 24

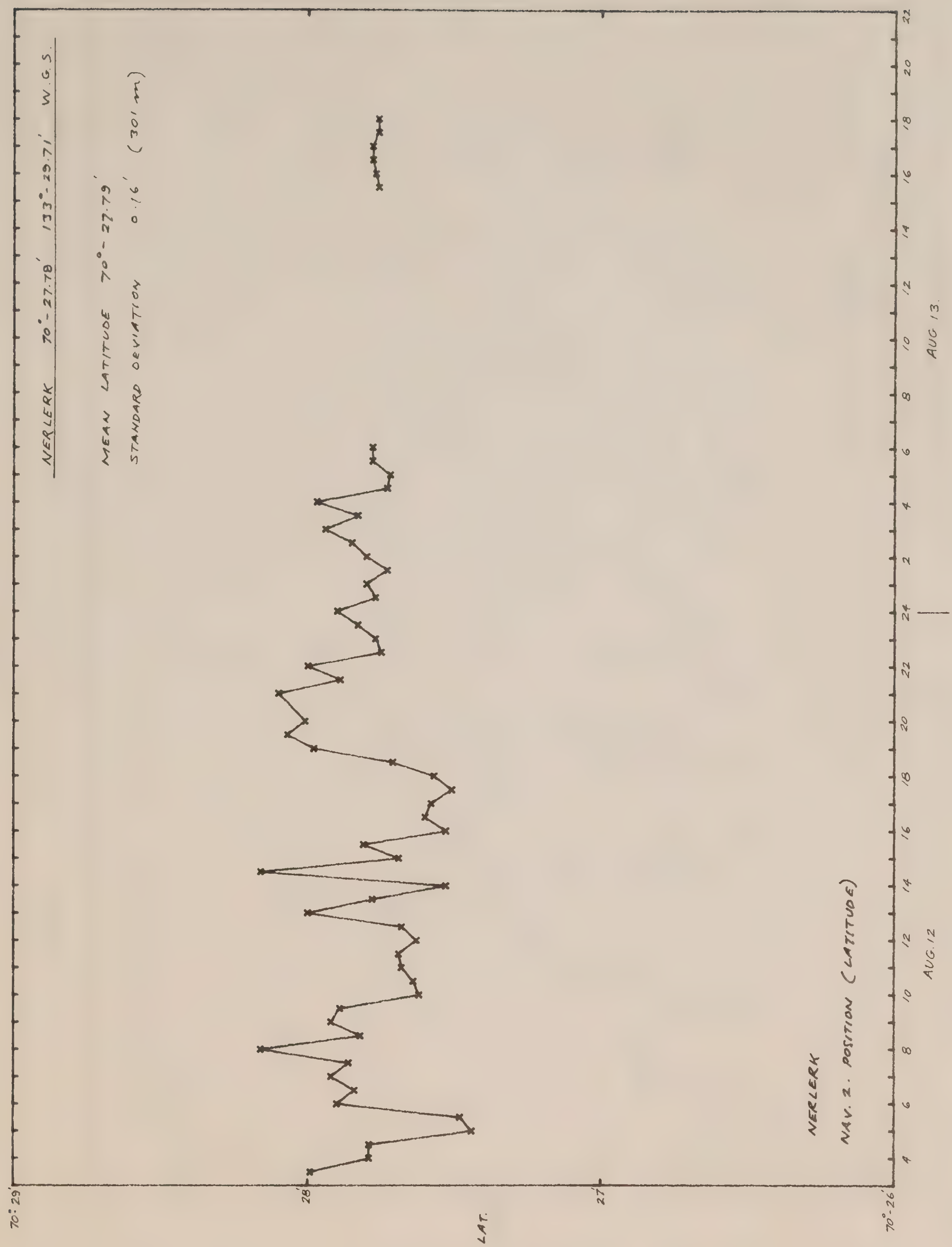
NERLERK 70°-27.78' 133°-29.71' W.G.S.
MEAN LATITUDE 70°-27.79'
STANDARD DEVIATION 0.16' (301 m)
NERLERK
NAV. 2. POSITION (LATITUDE)
AUG. 12
AUG 13
LAT.
70°29'
28'
27'
70°-26'
4
6
8
10
12
14
16
18
20
22
24
2
4
6
8
10
12
14
16
18
20
22

Figure 25

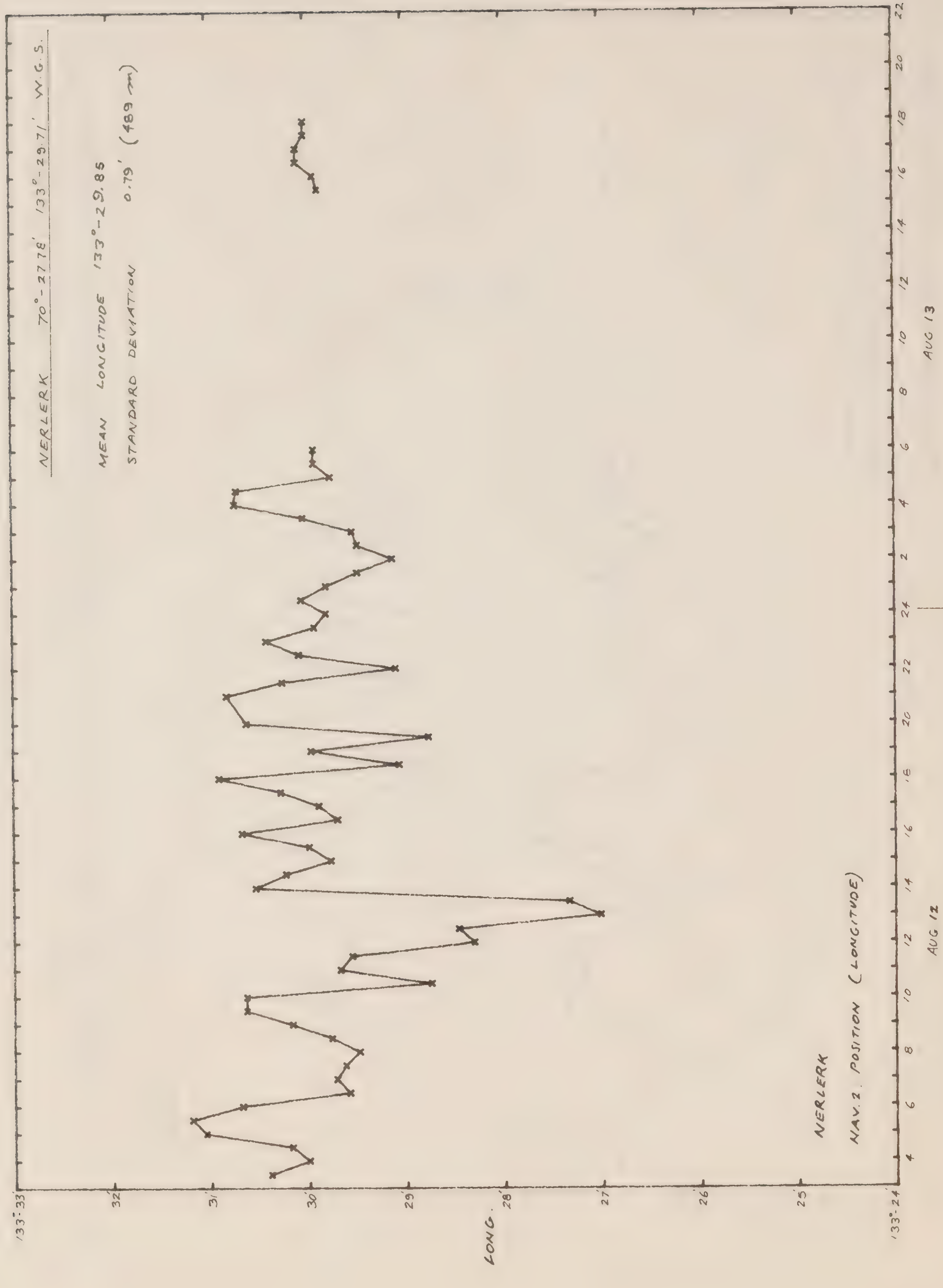
NERLERK 70°-27.78' 133°-29.71' W.G.S.
MEAN LONGITUDE 133°-29.85
STANDARD DEVIATION 0.79' (489 m)
NERLERK
NAV. 2 POSITION (LONGITUDE)
LONG.
AUG 12
AUG 13

Figure 26

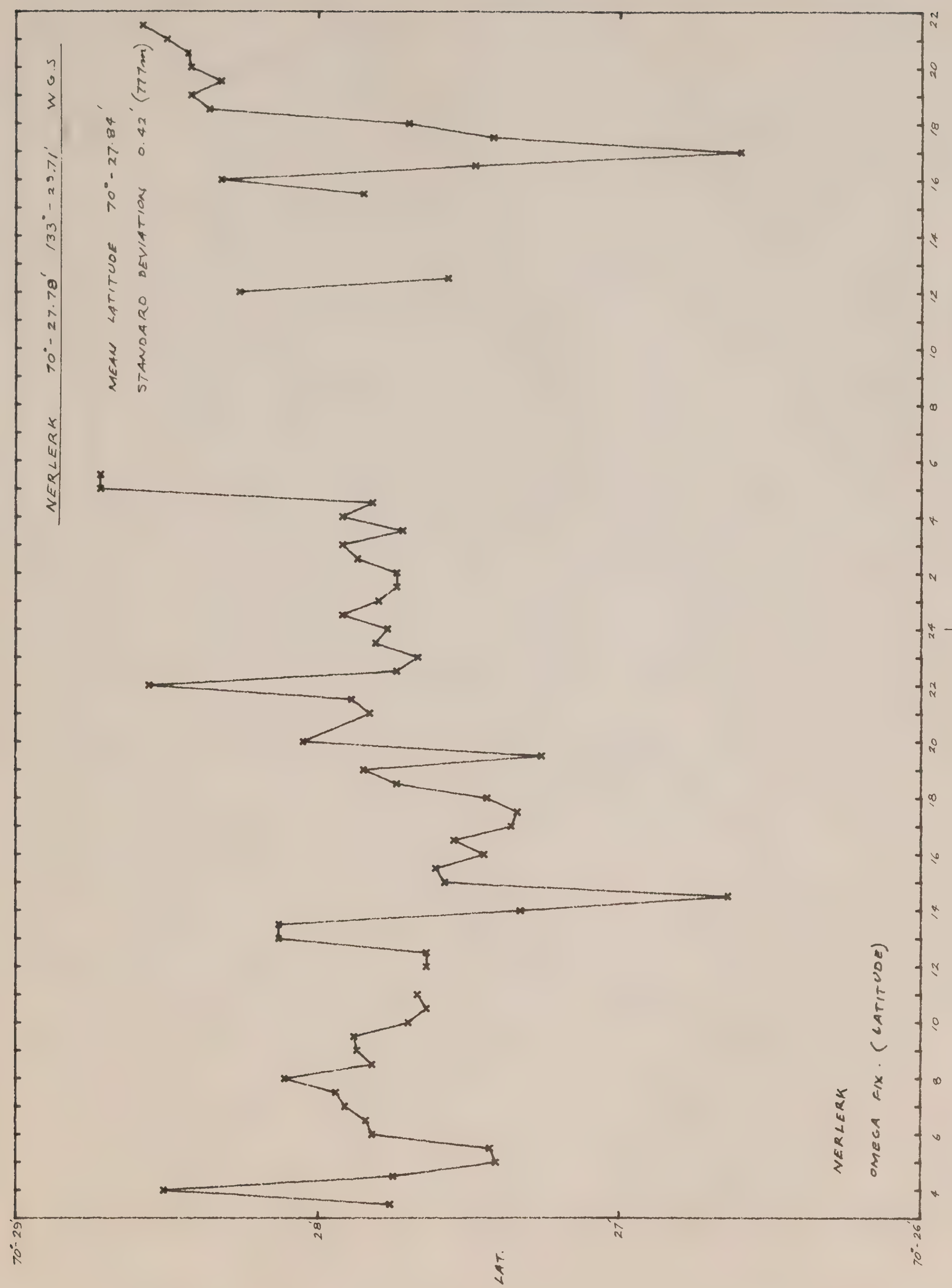
NERLERK 70°-27.78' 133°-29.71' W.G.S
MEAN LATITUDE 70°-27.84'
STANDARD DEVIATION 0.42' (777m)
NERLERK
OMEGA FIX. (LATITUDE)
AUG. 12
AUG. 13.
LAT.
70°-29'
28'
27'
70°-26'

Figure 27

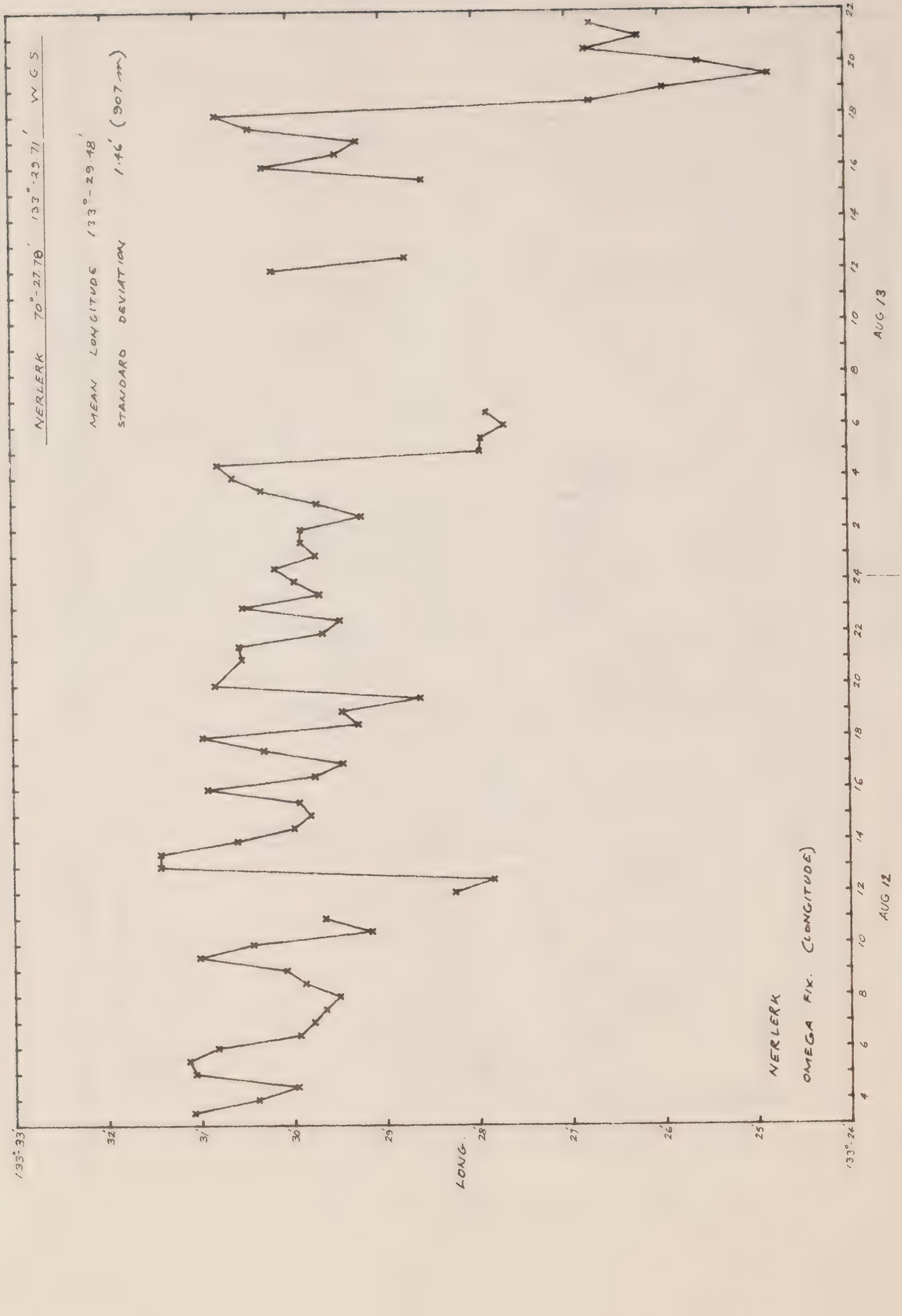
NERLERK 70°-27.70' 133°-29.71' W G S
MEAN LONGITUDE 133°-29.48'
STANDARD DEVIATION 1.46' (907 m)
NERLERK
OMEGA FIX. (LONGITUDE)
LONG.
AUG 12
AUG 13

Figure 28

Pacific Marine Science Report 80-6

DATA REPORT AND CALIBRATIONS FOR TURBULENCE MEASUREMENTS IN KNIGHT INLET, B.C. FROM THE *PISCES IV* SUBMERSIBLE: NOVEMBER 1978

by

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Sidney, B.C.

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Institute of Ocean Sciences

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DATA REPORT AND CALIBRATIONS FOR TURBULENCE MEASUREMENTS IN KNIGHT INLET, B.C. FROM THE *Pisces IV* SUBMERSIBLE: NOVEMBER 1978

by

A.E. Gargett

Institute of Ocean Sciences

Sidney, B.C.

1980

Abstract

The main purpose of this report is to archive calibration techniques and results for the set of sensors used on the *Pisces* IV submersible in November 1978. At that time, a series of measurements in Knight Inlet, British Columbia sampled turbulent velocity and temperature fields associated with three different regimes: a nonlinear internal wave train, a near-surface shear zone downstream of an internal hydraulic jump, and the shallow waters of the inlet in the absence of internal hydraulic events. Calibrated analog data is presented.

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1. Introduction

The complete turbulence system for the *Pisces* IV submersible has been under development for some years, since an initial major modification necessary to stabilize the submersible for mid-water running. Figure 1 documents the growth of a severe pitch instability after full power was applied to the thrusters used to propel *Pisces*. The amplitude of the pitching motion quickly reached ±20° and might have gone higher still: such tests were inevitably halted due to personnel discomfort. This instability has been completely removed by the design (by Dr. G. Parkinson of the Mechanical Engineering Department, University of British Columbia) of a set of removable stabilizing wings, shown schematically in Figure 2, and in a photograph (Figure 3) taken from the rear of the submersible. The plane of the flat control section of the wings can be varied between approximately -2 and +10 degrees from horizontal: small adjustments in wing angle allow the pilot to drive *Pisces* slowly up and down through the water column without adjusting the thruster angles, hence without changing the mean forward speed of the submersible through the water. Subsequent addition of an hydraulically controlled trim tab on one of the vertical sections of the wings (see Figure 3) allowed us to remove a slow directional drift which proved annoying in operations. With addition of this control apparatus, the submersible has proven a flexible vehicle for turbulence measurements; its motion through the water column is such that the mean forward speed is relatively constant and mean cross-flows at the sensor package are relatively small, except when it is necessary to carry out some manoeuvre such as change of horizontal direction or the rapid change of attitude required to avoid breaking the water surface at the top of a gradual ascent through the water column.

Sensors are mounted at the end of a forward strut (see Figure 2), as far forward of the personnel sphere as is operationally practical. The high-frequency turbulence sensors lead the rest (as shown in the insert to Figure 2), roughly 3 m in front of the personnel sphere. The direction of mean forward speed U is defined along the axis of the sensor package, positive toward the submersible; cross-axis flows are defined to complete a right-handed coordinate system with W positive upwards. These flows are measured at the location of the sensor package: signals from three small rotor current meters designated A, B, and C in Figure 2 are combined and rotated to given U, V, and W. A conductivity-temperature sensor C-TA, coupled with the depth gauge on the submersible, allows determination of mean temperature and salinity at the level of the high-frequency sensors, while an additional thermistor TB at a vertical separation of 0.8 m provides an estimate of the mean vertical temperature gradient. The high frequency sensors were mounted ∿ 0.33 m in front of these auxiliary sensors in the order shown in the insert to Figure 2. Axial component of velocity (u) was sensed with a heated conical platinum film probe, temperature (T') with a cold conical platinum film, and cross-flow velocity components (w and v) with two single-channel airfoil probes. These probes were mounted as close together as possible: separations were (u - T) = 0.6 cm, (T - w) = 3.7 cm, and w - v) = 1.8 cm. A set of three orthogonal accelerometers mounted immediately behind the high frequency sensors and a pressure gauge in a separate pressure case closer to the personnel sphere (neither shown in Figure 2) completed the instrumentation carried outside the submersible.

Voltages from all sensors entered the personnel sphere through an electrical penetrator, and were then digitized and recorded by a specially-designed data system (SCRIBE) which has been described in some detail by Galloway and Teichrob (1979).

This system was successfully used for the first time in November 1978 during a series of dives in Knight Inlet, one of the fjord-type inlets of the British Columbia coast. A submarine sill across the inlet produces a variety of internal hydraulic phenomena (Farmer and Smith, 1980) including a strongly nonlinear and highly turbulent internal wave train which progresses up inlet twice a day, shortly after the tide turns to flood across the sill. Although the internal wave train was the primary objective of this set of measurements, a few diving days were spent investigating flow downstream of the sill on the ebb tide, when a strong first-mode internal hydraulic jump was present over the sill itself (D. Farmer, personal communication).

The main purpose of this report is to archive calibrations of all the instrumentation used for the Knight Inlet measurements, including a discussion of calibration techniques when these are unique or not described in other publications. Lists of sensors, sample rates, dive locations, etc. are given as tables in the Appendix. Calibrations are found in Section 2, while Section 3 contains a brief discussion of dive locations and data quality as revealed by examples of (calibrated) analog records.

2. Calibrations

2.1 Heated platinum film: u

The axial component u of the turbulent velocity field is sensed with a heated platinum film probe. The sensing element is a thin ring of platinum deposited around a conical glass probe and protected by a very thin quartz coating. Electrical current passing through the platinum film raises its temperature above ambient by an amount ΔT referred to as the overheat. Fluctuations in current speed parallel to the probe axis produce fluctuations in heat transfer from the film, which may be sensed by a bridge designed to operate in either constant current or constant temperature mode. The latter is more appropriate for applications in the ocean, where plankton or detrital materials frequently lodge on the probe and greatly reduce the heat transfer: constant current operation would burn out the probe under these circumstances. Short probe lifetime due to sea-water corrosion of the platinum film has not been a significant problem since developments of quartz coating techniques for the probes and an AC bridge circuit (laboratory applications of hot-film techniques in fresh water invariably use DC bridges). We have used individual probes for many days of field operation. Indeed, we are still using probes from the set manufactured in the 1960s at the University of British Columbia for the Pacific Naval Laboratory (now DREP, Defence Research Establishment, Pacific), and used by Grant, Stewart and Moilliett (1962) in their pioneering measurements of high Reynolds number, turbulence in a tidal channel. These probes have stable calibrations (see calibrations of V30 in this section) and, if not physically damaged, will operate for many hours. One of these probes (V31) was mounted on a towed body for field trips in 1972 and 1973 and on the submersible for two operations in 1976. Estimated operating time in 1972-73 alone was greater than 120 hours, and this probe failed only when physically broken at the end of the autumn 1976 cruise. However, only two of these probes remain, and at present there seems to be no reliable source of stable probes: commercially available probes often exhibit unstable calibrations (see calibrations of TSI-8214, a Thermo-Systems Model 1230 W, in this section). It would seem advisable to examine the manufacturing process for reasons why these films are unstable in sea-water operation. One possibility is that the commercial process may not include a heat-treatment step which was found essential for stabilizing the UBC films after manufacture (A. Moilliett, personal communication).

For instrumenting the submersible, we had a choice of two constant-temperature bridges, both built at DREP, but designed for different operating conditions. The original bridge (Evans, 1963) was designed to be used in applications where the probe was physically close to the bridge. It was used by Grant *et al* (1962) with the probe on a towed body separated from the bridge by a short constant-length towing cable, and by Grant, Hughes, Vogel and Moilliett (1968) with the probe mounted on a submarine, again quite close to the bridge. A subsequent bridge was developed for use with a towed body designed to go to $\sim$ 400 m depth: the bridge circuit was incorporated into the towed body close to the probe, and controlled remotely by signals sent down the cable from a surface unit. With both power and space at a premium in submersible operations, we chose the original bridge which uses less power and occupies less space (due to the absence of the remote-control

capability, unnecessary in this application). This bridge (now nearly 20 years old!) has been described by Evans (1963). Briefly it is an AC feedback loop (12.5 Khz carrier frequency) which acts to maintain the probe at a constant number of degrees ΔT above ambient water temperature. A 500 ohm bridge is used, and the probe (roughly 5 ohm) is matched to the bridge by a 10:1 transformer located in the pressure case immediately behind the probe. The temperature coefficient of resistance α, determined for each individual probe by measuring its resistance as a function of known water temperature, is used to calculate ΔR_T, the resistance change corresponding to a given overheat ΔT. In operation, with the probe moving through water of temperature T_w, the bridge is first balanced (both resistance and capacitance), then the overheat resistance ΔR_T is added to the "cold" resistance of the probe and this "hot" resistance set on the bridge resistance arm. The servo-loop is then opened, and a final adjustment made to the reactive balance.

A block diagram of the submersible system is shown in Figure 4. The modulated 12.5 Khz output voltage from the bridge is converted to a fluctuating DC voltage and subsequently passed through a pre-whitening filter to boost high frequencies before digitization. The response characteristics of the system have been broken down into a sensitivity $G = S \cdot G_c \cdot G_w$ and a frequency dependence $g(f) = P(f) \cdot W(f)$, where

S in volts/(cm s^{-1}) is the sensitivity of the probe/bridge system (see 2.1.1 for measurement of S)

$G_c = 1.564$ is the converter gain at zero frequency

$G_w = 1.846$ is the filter gain at zero frequency

P(f) is the frequency response function of the probe/bridge system, normalized to 1.0 at zero frequency (see section 2.1.3 for measurement of P(f) and discussion of normalization) and W(f) is the measured frequency response of the pre-whitening filter, normalized to 1.0 at zero frequency. The converter response is flat to 500 Hz, the Nyquist frequency for measurements of u, and thus is not included in the response correction. Raw power spectral densities in units of $(\text{volts})^2$/cps are convected to physical units of $\left(\text{cm s}^{-1}\right)^2$/cps by dividing by $[G \cdot g(f)]^2$.

2.1.1 The hot-film as a mean flow sensor

Output from the hot-film bridge varies with the total flow past the sensor and thus contains mean flow as well as high frequency information. Considerations of dynamic range with a 16-bit A/D converter have resulted in the signal being split into two parts: the high gain channel (Ch.0) has the mean bridge voltage at an average operating speed removed, while the low-gain channel (Ch.1) has high frequencies removed by a low-pass filter with 3 db point at 0.5 Hz. This low-gain channel is vital to our ability to assess whether a platinum film is operating properly. If heated films do not operate properly as mean flow sensors, they are unlikely to produce

reliable data on high-frequency velocity fluctuations. We operate rotor current meters (see Section 2.6) to provide an independent estimate of the low-frequency components of forward speed, and find that when the heated film is not providing reliable low-frequency signal compared to the rotor current meters, the high frequency content is doubtful as well. An example was an observed difference between rotor-indicated speed and output from a TSI probe (using pre-cruise calibrations) which lead to its replacement during the field operation. Subsequent laboratory re-calibration showed a large calibration shift in both mean and sensitivity. Another frequent occurrence is an abrupt decrease of probe-indicated speed relative to rotor current meter speed, due to fouling of the platinum-film: the high frequency portion of the signal is unlikely to be any more reliable than the low-frequency part until the probe is somehow freed from the plankton or detrital material covering it.

Calibration of the probe/bridge output (rmsAC) as a function of steady mean speed U is carried out in a low turbulence level water tunnel at I.O.S.* Tunnel flow speed is measured with a Paro-Scientific differential pressure gauge (Model 215-D-002) which measures pressure across a 0.8 cm (5/16 inch) diameter Pitot tube placed approximately 15 cm from the hot-film probe. The gauge output is a period T which is measured by an HP 5326A timer-counter: U is then calculated as

$$U = C_v\sqrt{2gh} \quad \text{where} \quad h = A\left(1 - \frac{T_o}{T}\right) - B\left(1 - \frac{T_o}{T}\right)^2$$

(A, B and T_o are constants supplied with the gauge), and C_v is a constant depending on the Pitot tube, here taken as 1.0. Lacking an absolute measurement of tunnel speed, it is difficult to assess the error in this speed measurement. Least-bit fluctuation in the counter contributes an error of order ±(1.0 to 1.5) cm s^{-1} at speeds near zero, but is insignificant 100 cm s^{-1}. At higher speeds, errors arise through pressure gauge errors (leaks in tubes or O-rings, different temperatures of two legs of gauge, etc.) and the assumption of 1.0 for the Pitot-gauge constant. The latter is unlikely to result in more than ∿ 1-2% absolute error in speed since $0.99 < C_v < 1.01$ is almost always satisfied (Eckman, 1950). Random errors due to the pressure gauge are assumed to cause most of the spread in repeated calibrations of a stable probe such as V30, shown in Figure 5(a). Observed scatter of U values at fixed output voltages leads to a rough estimate of ±2 cm s^{-1} for relative error. The calibrations of V30 at 25°C overheat were carried out over a three month period spanning the field operation (in which the probe was operated for approximately 20 hours): the consistency of calibrations is remarkable. In contrast, Figure 5(b) shows calibrations of TSI-8214, a Thermo-Systems 1230W hot-film probe, before and after the same field operation (during which this probe was used for ∿ 24 hours). Some change in the probe caused by operation in salt water has resulted in a substantial decrease in mean voltage measured across the probe at a constant speed, as well as a change of curve shape resulting in a decrease of approximately 12% in zero-frequency sensitivity at a mean speed of 100 cm s^{-1}.

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2.1.2 Sensitivity calibrations

The probe/bridge sensitivity S is a function of individual probes, operating overheat, and mean speed. It has been determined by two independent methods. A static sensitivity S_o can be calculated from the inverse of the slope of the static calibration curve at the mean speed of operation, U_o. Coefficients of a fourth-order least-squares fit of the ensemble of calibrations of V30 are shown on Figure 5: the static sensitivity is

$$S_o = \left[\frac{dU}{d(\text{rmsAC})} \bigg|_{u_o} \right]^{-1} = \left[\sum_{i=1}^{4} i\, a_i (\text{rmsAC})^{i-1} \right]^{-1} \quad \text{volts/cm s}^{-1}$$

A second determination of sensitivity results from use of the vibrator, a device originally developed to measure P(f), the response of the probe as a function of frequency (see Section 2.1.3). The vibrator moves the probe parallel to its axis at set frequencies: the displacement, measured by a displacement transducer, is a sinusoidal function of time and thus the rms velocity v_{rms} of the probe can be determined from the measured rms displacement d_{rms}. The sinusoidal velocity fluctuation imposed on the probe results in a sinusoidal modulation of the carrier frequency, producing an rms output of rmsDC from the converter for an rms velocity input of $2\pi f\, d_{rms}$. As discussed in the previous section, the instantaneous voltage output from the converter is DC = 1.564(rmsAC); with a periodic input, DC = $\sqrt{2}$ (rmsDC), and thus the expression for the dynamic sensitivity is

$$S_D = \frac{\text{rmsAC}}{2\pi f\, d_{rms}} = \frac{1}{2\pi f\, d_{rms}} \frac{\sqrt{2}\,(\text{rmsDC})}{1.564}$$

where 1.564 is the zero-frequency converter gain. Sensitivities calculated by both methods for V30 are shown in Figure 6(a): the dynamic calibration was done at two frequencies, 30 and 50 Hz, to check that the method yielded a flat response over this range, as expected from the measured frequency response function (Section 2.1.3). The dynamic sensitivity is consistently about 7% higher than the static sensitivity. The dynamic calibration includes unsteady boundary layer effects, and thus is the correct unsteady sensitivity, while S_o is the correct zero-frequency sensitivity. The two measurements allow us to interpolate the response function (see next section) for frequencies between 0 and 20 Hz. Similar results are presented for the Thermo-Systems probe TSI-8214 in Figure 6(b): the static and dynamic sensitivities agree to within the experimental scatter, implying that the response is flat between 0 and 30 Hz.

The hot-film is a highly non-linear speed sensor, and a full non-linear calibration must be used in applications involving large speed changes. One of the advantages of the submersible operation is that mean forward speed is generally constant to within $\sim \pm 5$ cm s^{-1} and fluctuating levels at frequencies greater than 1 Hz seldom exceed ± 1 cm s^{-1} (see Section 3 for typical records). Under these circumstances, the approximation of constant gain, i.e. local linearity, of the sensor allows us to save a great deal of computational time while introducing errors less than those involved in the experimental determination of sensitivity.

2.1.3 Frequency-response calibration

The response of conical hot-film sensors is not necessarily flat as a function of frequency. Leuck (1979) has examined unsteady boundary layer effects which give use to various response curves depending upon probe geometry. For the older UBC films, he is able to predict the rise in response at high frequency which Grant *et al* (1962) determined experimentally. Using the technique (and indeed the apparatus) of Grant *et al*, we determine P(f) for each individual probe by shaking it sinusoidally along its axis at different frequencies. The rmsDC bridge voltage out of the converter is divided by $2\pi f\, d_{rms}$, the rms velocity experienced by the probe vibrating sinusoidally at frequency f through an rms displacement d_{rms}. The response function should be normalized by its value at a very low frequency, but the vibrator cannot produce accurately sinusoidal displacements at frequencies much below 20 Hz, so the response functions as plotted in Figure 7 are normalized by their values at a point within the flat-response region (40 Hz for V30, 20 Hz for TSI-8214).

The vibrator measurement is somewhat sensitive to vibrator gain settings, apparently because some combinations of frequency and drive amplitudes cause small cross-axis resonant vibrations. Thus the points in Figure 7(a), two calibrations for V30 at 80 cm s^{-1} and one at 100 cm s^{-1} mean flow speed, show some scatter, larger at higher frequencies. Although the response should be a weak function of mean speed, the measurements are not good enough to justify different response curves as a function of U. We have drawn a curve through the aggregate of points as a best approximation to P(f); typical errors due to speed variations and/or experimental error, amount to $\sim \pm 2.5\%$ for frequencies $f > 100$ Hz, $\sim \pm 1\%$ for $f < 40$ Hz.

The same calibration for TSI-8214 (Figure 7(b)) illustrates the difference in response curves produced by different geometry: this response function slowly decreases to a minimum around 150 Hz, then rises with higher frequency, but much less rapidly than V30.

To obtain the response function for V30 over the 0-20 Hz range in which the vibrator doesn't operate properly, we interpolate linearly between $P(20\text{Hz}) \equiv 1.0$ and $P(0\text{ Hz})$ = response at zero frequency normalized by response at 40 Hz = S_o/S_D. Based on the ratio of static to dynamic sensitivities of V30 in the range of 80-100 cm s^{-1} mean speed (Figure 6(a)), a reasonable value for $P(0\text{ Hz}) = 0.9$. The probe/bridge response function

can then be re-normalized to 1.0 at zero frequency (see Table 1). The high-frequency response of the system is further enhanced by a pre-whitening filter, with frequency response W(f) as shown in Figure 8. Spectral values are corrected for the response characteristics of probe/bridge and pre-whitening filter by linear interpolation in Table 1 of combined response R at standard frequencies.

TABLE 1: V30: Response functions of the probe/bridge system P(f) and pre-whitening filter W(f) at standard frequencies.

f (Hz)	P(f)*	$P_o(f)^\dagger$	W(f)	$R = P_o(f)\ W(f)$
0	(0.9)	1.0	1.00	1.00
5		1.03	1.02	1.05
10		1.06	1.12	1.19
20	1.00	1.11	1.45	1.61
30	1.00	1.11	1.88	2.09
40	1.00	1.11	2.29	2.54
50	1.00	1.11	2.81	3.12
75	1.05	1.17	4.03	4.72
100	1.09	1.21	4.64	5.61
150	1.17	1.30	7.60	9.88
200	1.25	1.39	10.0	13.9
250	1.32	1.47	12.4	18.2
280	1.35	1.5	12,7	19.1
300	1.38	1.53	12.5	19.1
350	1.42	1.58	11.1	17.5
400	1.47	1.63	9.13	14.9
450	1.49	1.66	5.63	9.34
500	1.51	1.68	3.39	5.70

* original measurement of probe/bridge response normalized to 1.0 at 40 Hz: the value in parentheses at 0 Hz is the ratio $S_o/S_D = 0.9$ of static to dynamic sensitivities (see Section 2.1.2).

† probe/bridge response re-normalized to 1.0 at 0 Hz.

2.1.4 Angular response

The response of the conical film probe is almost flat as a function of the total angle of attack Θ between the probe axis and the mean speed $\underline{U}$, as can be seen for V30 in Figure 9. This is a useful property if the aim is to measure fluctuations due to isotropic turbulence from a platform, such as a towed body, which might often develop sizeable angles between probe axis and mean speed, conditions typical of the original Grant *et al* (1962) tidal channel measurements, and subsequent (Grant *et al* (1968)) measurements from a submarine in the surface mixed layer under waves. However, if the aim is to investigate isotropy, one would much prefer a cosine response as

a function of angle, i.e. a true axial speed sensor. Because of this property of the conical hot-film probe, in addition to constraints on airfoil probe linearity as a function of Θ (see Section 2.3), it is essential to measure the total angle of attack and restrict investigation of the degree of isotropy of the small-scale velocity field to regions where Θ is small. If we imagine a totally anisotropic situation with $w \equiv v \equiv 0$, then deviations of the probe axis of 5°, 10°, and 15° from the direction of the mean and fluctuating flow (U + u) result in over-estimating the true axial mean square fluctuating component by 1%, 3% and 7% respectively. Requiring $\Theta < 10°$ should be a sufficient criterion, since isotropic fields should yield differences of $\sim$ 30% between spectral values of axial and cross-axis velocity components. This restriction involves very little loss of data in the situations in which we have used the submersible up to the present.

2.1.5 Temperature sensitivity

The question of contamination of heated anemometer measurements by temperature changes in the surrounding fluid is of particular importance to oceanic measurements, where small-scale temperature fluctuations almost always accompany velocity fluctuations. Since the temperature of water in the large tunnel at I.O.S. cannot be varied, we measured the zero frequency temperature sensitivity of V20 by the equivalent procedure of changing probe overheat (difference between probe and water temperatures) with constant water temperature. The resulting changes in output voltages correspond to apparent velocity changes of $\sim$ 15 cm s^{-1} per °C. This zero frequency temperature sensitivity determines how well the hot film will perform as a mean flow sensor in a fluid of changing mean temperature. However for the high frequency range of the velocity signal, the relevant parameter is the change in dynamic probe sensitivity S_D (see Section 2.1.2) as a function of mean water temperature. Again by changing the probe overheat with constant water temperature, this time with the probe vibrated at 40 Hz, we measured a change S_D of ±3.5% per Centigrade degree change in water temperature, with the 25°C overheat and 100 cm s^{-1} mean forward speed typical of submersible operations.

2.2 Cold platinum film, T'

High frequency temperature fluctuations were measured with an unheated conical platinum film sensor (Thermo-Systems Model 1230T) on which the film covers the tip of the cone. Since some current must pass through the film in order to sense resistance changes due to temperature fluctuations in water moving past the sensor, the film is not truly "cold", and thus might have some small sensitivity to velocity. Positioning the film near the stagnation point of steady flow past the cone helps reduce the velocity sensitivity. We have tested our cold films in the vibrator used for velocity calibration of heated films (Section 2.1) and find no measurable change from steady flow output: the degree of velocity contamination of the cold-film temperature measurement is negligible.

The original bridge for platinum resistance probes was designed at the Pacific Naval Laboratory (now Defence Research Establishment, Pacific) in the early 1960's (Grant *et al*, 1968). It was redesigned in 1976 by the Ocean Mixing Group at I.O.S., to be compatible with the space/power limitations of *Pisces* IV. The present bridge uses a platinum film probe, with a resistance in the range of 5-10 ohms, as one leg of an a.c. bridge driven by an amplitude-stable 11.2 KHz oscillator (Figure 10(a)). The actual bridge, bridge driver and detector are located in an underwater pressure case immediately behind the probe, in order to minimize probe lead resistance. Remaining circuitry is situated within the manned sphere of the submersible. Approximately 50 mV rms is applied across the probe, and then Z_b (Figure 10(a)) is adjusted to give an approximate bridge balance at the mean water temperature T_w. The bridge can then be pseudo-balanced at any temperature within a range $\pm T_R$ about T_w, by summing the amplified bridge signal with a reference consisting of the oscillator voltage adjusted manually in both phase and amplitude. Output of the summing amplifier appears to be that of a balanced bridge, as any change in temperature of the probe produces deviations from the null point of the summing amplifier. Final output from the bridge is a DC voltage with a variable gain of G = 1, 2 or 4 times A_o, the zero-frequency gain of the basic probe/bridge system. Further processing includes a high-pass filter with 3 db point at $\sim$ 0.5 Hz and a constant gain of 11 in the pass band, and a pre-whitening filter with a gain of 2 at zero frequency and frequency response W(f) shown in Figure 8 (and listed at standard frequencies in Table 1). A simplified block diagram of the whole system is shown in Figure 10(b). Probe/bridge characteristics of zero frequency sensitivity A_o and frequency response function A(f) are determined experimentally as described in the following sections. Raw power spectral densities for temperature $\phi_r(f)$ (volts^2/cps) are converted to physical units and corrected for response functions as follows:

$$\phi_T((°C)^2/\text{cps}) = \frac{\phi_r(f)(\text{volt}^2/\text{cps})}{[S_o \cdot S(f)]^2}$$

where $S_o = A_o \cdot G \cdot 11 \cdot 2$ is the zero-frequency gain, and $S(f) = |A(f)| \cdot W(f)$ is the frequency response function (normalized to 1.0 at zero frequency) of the system.

As used in 1978, this bridge showed an undesirably high level of electrical noise at frequencies above 100 Hz, affecting the calculation of rate of dissipation of temperature fluctuations: this noise is not evident in the chart records presented in Section 3, since the chart recorder effectively filters out frequencies above ∿ 100 Hz.

2.2.1 Sensitivity calibrations

The zero-frequency sensitivity of the sensor/bridge system is measured (with G = 1) with the probe soldered into its final configuration on PISCES, because probe resistance (∿ 5-10 Ω) is small enough that changes in lead resistances before the bridge can significantly affect the calibration. The probe is immersed in vigorously-stirred water in an insulated flask and calibrated against a Hewlett-Packard quartz thermometer, starting from ice-point and working over about a 10°C range. Even on the lowest gain setting, the temperature circuit traverses full scale (±10 volts) over ∿ 3°C range; the bridge is re-balanced each time full-scale is reached, so that a typical calibration consists of two or three separate sections. Since the zero-frequency sensitivity A_o is the slope of this linear calibration, we may average the slopes obtained by a least-squares linear fit to each individual section, or use such a fit to normalize each section to relative temperature $(T - T_o)$, then determine a slope from the ensemble of points. The results are equivalent to within 0.1%, and we have chosen the latter procedure because it allows us to present duplicate calibrations more easily. Figure 11 presents two field calibrations of the cold-film, before the start of the Knight measurements (Nov. 8) and one day before the end of measurements (Nov. 22). The two sets show a 5% difference in A_o; we choose to use the final value of A_o = 0.408448 volts/°C since this was closest in time to most of the measurements.

2.2.2 Frequency-response calibrations

The frequency response of the cold-film/bridge system was determined by the plume tank method originated by Fabula (1968), as subsequently refined by Hughes (see Appendix to Fabula, 1968). A thermistor is tracked slowly (U_{th} = 0.02 cm s^{-1}) through the steady narrow convective plume rising from a single heated wire stretched across a calibration tank. The thermistor is then removed and the cold-film probe is shot across the plume at a constant speed U_p which can be varied from a few centimetres to a few metres per second. The ratio of the power spectral density of the platinum thermometer signal to that of the thermistor signal (scaled in frequency to allow for the different speeds at which the two probes traverse the constant domain in physical space) then yields $A(f) \cdot A^*(f)$, the square of the magnitude of the (complex) platinum response function $A(f)$. According to the theory of Fabula,

$|A(f)| = e^{-\sqrt{\frac{\Delta^2}{K}\pi f}}$ where f is frequency in Hz, K is the thermal diffusivity of water, and Δ is a length scale of the order of the velocity boundary-layer thickness over the film. Thus a plot of $\ln|A(f)|$ against $(f)^{\frac{1}{2}}$ should yield a straight line through (0,0) with slope $-\left(\frac{\Delta^2}{K}\pi\right)^{\frac{1}{2}}$, from which the parameter Δ may be determined for each particular cold-film probe at the roughly 100 cm s^{-1} operating speed of *Pisces*. Figure 12 shows such a plot for the probe (TS-T1) used in the Knight Inlet measurements. The straight line yields a value of Δ = 0.00217 cm (using $K = 1.44 \times 10^{-3}$ cm^2 s^{-1} for fresh water at $\sim$ 20°C). Plotted points fall below the curve at high frequencies due to a 300 Hz low-pass filter in the temperature bridge. We do not yet know the reason why the lowest frequency points lie above the line.

2.3 Airfoil probe: v and w

2.3.1 Principle of operation; sensitivity calibration

Details of the manufacture and operation of the original (two-axis) airfoil probes for use in the ocean have been given by Osborn and Crawford (1977). On PISCES, we used single-axis probes manufactured at the Institute of Oceanography, University of British Columbia, and most kindly provided for the operation by Dr. T.R. Osborn. The single-axis probe is a single piezo-ceramic beam mounted in a hollow stainless-steel tube, over which is moulded a soft expoxy nose-piece which waterproofs the sensing element while still allowing it to bend freely. As the beam bends under the aerodynamic lift produced on the probe tip by fluctuating velocities, the resulting voltage between the two sides of the beam is sensed by the probe electronics, producing an output voltage E proportional to F, the total cross-force acting on the probe tip. Inviscid potential flow theory for a slender body of revolution (Allen and Perkins, 1952) yields the following expression for F:

$$F = \left(\frac{1}{2}\rho U^2\right) A \sin 2\alpha \qquad (1)$$

where $A = \int_0^L \frac{dA}{dx}\, dx$ is the integral of the rate of change of cross-sectional area from the probe tip at x = 0 to a point x = L at which the diameter becomes constant, U is the mean speed parallel to the probe axis and α is the instantaneous angle of attack of the total velocity vector $\underline{U}_T$. For small angles α, i.e. for $v \ll U$ in Figure 13, $\sin 2\alpha \simeq 2v/U$ and expression (1) reduces to

$$F \simeq \rho A U v \qquad (2)$$

from which it is evident that the airfoil probe senses cross-stream velocity fluctuations. The relationship

$$E = \rho S U v$$

defines a probe sensitivity S (in units of volts/(g cm^{-3})(cm s^{-1})^2 which is a function of the individual probe and the gain of the associated electronics. S was determined experimentally for each probe before and after the cruise. Osborn and Crawford (1977) describe the calibration technique, which consists of rotating the probe at constant frequency (2.5 Hz) in a submerged water jet of constant speed U_j. If α = the angle between probe and jet axis, and E_{rms} = the root mean square value of the sinusoidal voltage variation produced as the probe tip rotates in the mean flow, measured by a true rms voltmeter, then

$$E = \sqrt{2}\, E_{rms} = \rho\, S\, U_j\, v \simeq \frac{\rho}{2} U_j^2\, S \sin 2\alpha \tag{3}$$

using the small angle approximation for sin 2α. Thus, if m is the slope of a graph of $E_{rms}/\rho\, U_j^2$ as a function of sin 2α, the probe sensitivity is

$$S = 2\sqrt{2}\, m$$

Figures 14(a) and (b) show calibrations for the two probes used in Knight Inlet, distinguishing between calibration points from before (+) and after (⊙) the cruise. Within the accuracy of the calibration technique (±5% is claimed by Osborn and Crawford (1977)) and the slight variations between the two independent calibration sets, the linear relationship given by (3) is seen to provide a good fit for angles of attack less than ∿ 12° (sin $2\alpha \leq 0.4$). The straight lines are linear least squares fits to data points with sin $2\alpha \leq 0.4$; their slopes m_i are used to calculate probe sensitivities S_i.

The electronics used in PISCES had variable gain. Measured gains at the switch settings used during the field work are shown in Table 2: the setting normally used was G = X5.

TABLE 2: Standard gain settings used in airfoil probe electronics.

AIRFOIL PROBE Channel No.	GAIN SETTING X1	X2	X5
1	10.4	20.5	51.7
2	9.9	19.8	49.9

The voltages E_i output from the shear probes were converted to physical units of cm s^{-1} by the relationships

$$w = \frac{E_1}{\rho U S_1 G_1}$$

$$v = \frac{E_2}{\rho U S_2 G_2}.$$

where U = mean forward speed of submersible from rotor current meters (Section 2.6), $S_i = 2\sqrt{2}\, m_i$ = probe sensitivity, G_i = channel gain, and ρ is the density of seawater, taken as 1.02.

2.3.2 Effect of temperature on probe sensitivity

The airfoil probes were calibrated in water of mean temperature ∿ 22°C; since water temperature in Knight Inlet was typically ∿ 9°C, the probe sensitivity has been corrected for an increase of ∿ 0.5% per °C below calibration temperature (T. Osborn, personal communication), using mean temperature measured by thermistor B.

$$\left(S_i\right)_{TB} = \left(S_i\right)_{T_{cal}} \left(1 + 0.005(T_{cal} - TB)\right)$$

2.3.3 Frequency/(wavenumber) response

The frequency response of the probe itself is not well known at present. Osborn and Crawford (1977) report that standard calibration is done with a rotation rate of 2.5 Hz, and that doubling this frequency produces no change in output, suggesting that the response is flat to at least 5 Hz. Calibration against a laser-doppler system is presently being attempted (Osborn, personal communication). The shear circuits contain a high-pass filter, down 3 db at 0.5 Hz, which was included to remove any low frequency temperature-induced effects, rapidly rising and more slowly decaying offsets observed when a probe passes through a strong fine structure temperature gradient during usual vertical free-fall deployment. Since the PISCES path through the water is nearly horizontal and the ocean stratification is mainly vertical, the effective gradients encountered are much smaller and temperature-induced effects are seldom noticed. Low frequency roll-off due to this filter is removed in spectral processing.

2.4 Conductivity

Conductivity was sensed with a freely flushing sensor similar to that described by Nasmyth (1970). Two pairs of field electrodes, spaced $\sim$ 0.2 cm apart, are supplied with constant current: changing resistance of the seawater path between the electrodes produces a fluctuating voltage which is sensed by a pair of pick-up electrodes located between the field electrodes. The sensor is calibrated by measuring the output voltage (V) as a function of temperature (T) with the sensor submerged in a well-stirred bath of constant salinity water. Salinity S is determined from water samples using a Guildline Auto-Salinometer, while T is measured by a Hewlett-Packard quartz thermometer. Conductivity (C) is then calculated from measured S and T, using the algorithm developed by Ribe and Howe (1967) with $p = 0$. The bridge output voltage is a highly linear function of resistivity $R = 10^3/C$. Unfortunately, during the 1978 field operation, the sensor and bridge system had some still undetermined fault which caused sizeable offsets among calibrations carried out in the laboratory (Oct. 6/78), and in the field before (Nov. 7/78) and after (Nov. 20/78) measurements: these three calibrations are shown in Figure 15. We have two reasons for using the last calibration, carried out in Knight Inlet immediately after the end of field observations. First, we suspect that the fault lies in some sensitivity of the bridge to mean temperature, and the air temperature in Knight Inlet was closest to measured water temperature; secondly, at times when *Pisces* was operated in the vicinity of the profiling Guildline CTD system used on the *Vector* by the Coastal Zone Oceanography group of I.O.S., salinities calculated with the Nov. 20 calibration agree reasonably well. We use the salinity measurement only qualitatively.

2.5 Thermistors

Two thermistors were carried on *Pisces*. TA, at the level of the high-frequency sensors, was mounted in the throat of the through-flow conductivity sensor described in the previous section, and used with measured conductivity and pressure to calculate salinity. TB was mounted $\Delta z = 0.8$ m vertically above TA; the value of $(T_B - T_A)/\Delta z$ provides a reasonable estimate of the vertical temperature gradient, given the low path angles to horizontal which are typical of submersible operations.

The two thermistors employed had different characteristics. TB, a VECO 32A91 glass bead thermistor with $\sim$ 0.02 s time constant (Fabula, 1962) maintained mean calibration against a quartz thermometer over the period of measurement. Figure 16 shows before (⊙) and after (+) calibration points, and a linear least squares fit to the combined calibration data.

In all previous work, a similar thermistor had been used in the conductivity head, but for this cruise it was replaced by a Thermometrics A1B10 micro-bead, in an attempt to decrease the response time of the temperature measurement to match that of the conductivity sensor more closely. Unfortunately, the epoxy used to mount these new thermistors absorbed water under pressure, resulting in frequent calibration shifts of T_A. When the problem was identified, about half way through the Knight Inlet measurements, the fast-response thermistor was replaced by another similar to T_B; a fit to the combined calibrations of this thermistor (No. 22) upon mounting (Nov. 15th) and after completion of the cruise (Nov. 20th) is shown in Figure 17.

Calibrations of fast-response thermistors (No. 1 and No. 2) at various times during their periods of operation show that the main effect of water absorption in the epoxy was a zero-shift of calibration rather than a gain change (see Figure 18(a) and (b)). For those records affected, I have corrected the zero-temperature of T_A by comparing the output to the stable-calibration T_B in a region of low vertical temperature gradient, identified on the basis of no change in T_B (to ±0.025°C) as the submersible travels slowly up or down: for gain, I have used the average of the results for available calibrations. Such an *in situ* calibration against T_B is certainly sufficient to remove the roughly 0.5°C offset evident between the Oct. 10/ Nov. 7 and the Nov. 12 calibrations of thermistor No. 1, for example. However, it is difficult to decide on the real error involved in such a procedure. It seems likely that the value of T_A, thus corrected, has $\sim$ ±0.05°C absolute accuracy and $\sim$ ±0.015°C relative accuracy.

2.6 Rotor current meters; U, V and W

Mean forward speed U through the water must be known accurately, as it affects the high-frequency measurements in two ways. The gains of both the heated-film and airfoil velocity probes depend on U, and the mean speed of water past the probes is used to convert from the time domain of measurement to the space domain in which theoretical predictions are formulated. In addition, measurements of the mean cross flows V and W are necessary to identify periods when the angle of attack Θ of the mean flow exceeds limits over which the airfoil probes have constant gain and the platinum film acts as an axial speed sensor. On *Pisces*, these mean flow components are measured with a set of 1.9 cm diameter ducted rotors developed by J.D. Smith of the Oceanography Department, University of Washington (for a description of the sensor and circuitry, see Smith, 1974). The rotors are mounted in such a way that a substantial component of the large mean forward speed is sensed by each rotor, eliminating threshold problems. With small corrections, discussed under angle-of-attack corrections below, each rotor is essentially a speed sensor measuring the component of flow parallel to the rotor axle. Rotor axle configuration relative to the axis OX of the high-speed sensors is shown in Figure 19(a). Figure 19(b) shows a head-on view of the rotor arrangement. Measurements of speed along the three non-orthogonal axles (heavy lines at A, B, and C) can be combined to give components of velocity in the submersible coordinate system as defined in Figure 2 to result in a positive value for U = speed of water parallel to high-frequency probe axes. If u_A, u_B and u_C are the speeds parallel to the A, B and C current meter axles, then

$$U = \frac{u_A + u_B + u_C}{3 \cos 35°}$$

$$V = u_B - u_C$$

$$W = \frac{u_A - \frac{1}{3}\left(u_A + u_B + u_C\right)}{\cos 55°} = \frac{2u_A - u_B - u_C}{3 \cos 55°}$$

The total angle-of-attack Θ, defined as the angle between the mean velocity $\underline{U}_T$ and the axis of the high-frequency probes, can then be calculated as

$$\Theta = \sin^{-1}\left[\left(\frac{V^2 + W^2}{U^2 + V^2 + W^2}\right)^{\frac{1}{2}}\right]$$

2.6.1 Head-on calibrations

At zero angle-of-attack, the calibration equation for a single rotor is

$$u = a + mf$$

where u is the flow speed parallel to the rotor axle, a and m are empirical constants, and f is output frequency

$$f = \frac{100106}{\text{COUNT}} = \frac{100106}{32767 + \text{D.U.}}$$

measured by a digital circuit which increases COUNT by 1 every rotor revolution.

Individual rotor calibrations against flow speed in the I.O.S. water tunnel are shown in Figure 20(a) to (c). The points from separate calibrations carried out before (+) and after (⊙) the cruise agree to within $\sim \pm 0.5$ cm s^{-1} and have been combined for the determination of calibration constants a and m given in Table 3.

TABLE 3 Calibration constants for the three rotors used during Knight Inlet measurements

	Rotor No.	a	m
RCM A	1	1.8848	6.8326
B	5	1.8593	6.7156
C	2	1.7914	6.7990

The mean forward speed of the submersible is approximately 100 cm s^{-1}; since each rotor thus senses on average 100(cos 35°) cm $s^{-1} \approx$ 80 cm s^{-1}, error due to the head-on calibration is $\sim (\pm 0.5/80) \times 100\% \approx 0.6\%$.

2.6.2 Angle-of-attack corrections

Small additional errors arise because the ducted rotors do not have a perfect cosine response, that is, do not sense exactly $U_T \cos\Theta$ if a mean velocity $\underline{U}_T$ makes an angle Θ with the current meter axle. The true axial speed u can be expressed as:

$$u = u_R\, g(\Theta) = (a + mf)g(\Theta)$$

where u_R is the speed registered by the rotor and $g(\Theta)$ is an empirical function. If the angles Y = yaw angle of rotation from head-on about the current meter stem, P = pitch angle from head-on in the plane of the stem, and Θ = total angle of attack are defined relative to a calibration coordinate system with x-axis parallel to a steady mean flow as shown in Figure 21(a) to (c), the function $g(\Theta)$ is defined as

$$g(\Theta) \equiv \frac{U \cos \Theta}{a + mf}$$

where $\Theta = \tan^{-1}\{(\tan^2 Y + \tan^2 P)^{\frac{1}{2}}\}$ (see Figure 21(c)) and U is the mean calibration water speed. This definition is such that $g(\Theta)$ equals 1 for a perfect cosine response. Our rotors tend to overspeed slightly ($g(\Theta) < 1$) for the moderate angles of attack typical of the submersible application.

The surface $g(\Theta) = g(P,Y)$ is shown schematically in Figure 22. In practice, since the mean forward speed of the submersible greatly exceeds typical cross-flows, variations in angle-of-attack are generally less than 10°, and it is only necessary to define the shape of $g(\Theta)$ close to the mean yaw and pitch angles. $\overline{Y}$ and $\overline{P}$ for each rotor, as determined by its mounting configuration and the assumption of zero cross-flow, are noted in Figure 22. Angle calibrations for each rotor will be presented as three sections (shown schematically in Figure 22 for the B current meter): $g_o(0,Y)$ which will be used to determine a zero-correction for yaw angle Y as described below; $g_Y(\overline{P},Y)$, a section parallel to the yaw axis at $\overline{P}$ = mean pitch angle of rotor; and $g_P(P,\overline{Y})$, a section parallel to the pitch axis at $\overline{Y}$ = mean yaw angle of the rotor.

A special calibrator has been designed to fit the I.O.S. water tunnel, allowing calibrations in the range $-50° < Y < +50°$ and $0 \leq P < 50°$. Pitch angle is measured with an accelerometer attached to the current meter stem (see Section 2.7 on accelerometers) and should be accurate to a fraction of a degree. A satisfactory measurement of yaw angle is more difficult without gravity to provide a convenient and repeatable zero. Rotating the current meter head to obtain maximum output serves to align the rotor approximately parallel to the flow, to ±2° say, but zero errors of this amount lead to noticeable asymmetries in the response curves. From the original calibrations of similar rotors in the University of Washington towing tank where the mean flow, produced by movement of a carriage, is accurately parallel to the rotor axle, we know that the response function is a symmetric function of yaw. Thus we have chosen to key the approximate zero yaw position at the beginning of each set of angle calibrations (ensuring that the rotor returns to the same, even if slightly incorrect, zero position for all calibrations), and determine a zero correction Δ for yaw by requiring that the yaw calibration be symmetric about zero. For example, Figure 23 shows the effect on the original $g_o(0,Y)$ (+) of assuming zero errors of -1° (•) and -2° (o) in Y: the choice of -1° makes the calibration reasonably symmetric, while -2° forces an asymmetry opposite to the original. Thus, we choose $\Delta = -1°$ and in all subsequent calibrations of the same rotor, apply this correction to Y (measured on a protractor accurate to ±0.5°).

The set of three calibration sections for each current meter is given in Figure 24(a) through (c). The value Δ of the zero correction which has been used for yaw is noted on Figure 24(a). We mention two things about this calibration. First, it is extremely repeatable, implying that the zero error in yaw indeed remains constant as long as the rotor is not removed from the calibrator. Secondly, the value of $g_o(0°,0°)$ is a very sensitive indicator of the long-term stability of the head-on calibration of these rotors. Using calibration coefficients a and m determined at the time of the 1978 sea trip, the value of $g_o(0°,0°)$ in these late 1979 angle calibrations is within 1% of the expected value of 1.0.

The other two relevant sections are plotted in Figure 24(b) and (c). Note that values of $g(\Theta) = g(\overline{P},\overline{Y})$ at the mean $\overline{P}$ and $\overline{Y}$ values appropriate for each current meter agree to within ±1% between the two calibrations. Averaged over a sufficiently long piece of record, $\overline{V} = \overline{W} = 0$, and hence mean speed $\overline{U}$ can be calculated to ±1% using $g(\overline{P},\overline{Y})$ only: values used are $g_A(35°,0°) = 0.985$, $g_B(20°,30°) = 0.945$ and $g_C(20°,-30°) = 0.960$. However, for spectral processing of orthogonal velocity components, the lines or curves drawn through $(\overline{P},\overline{Y})$ on each section are used to correct $g(\Theta)$ for small angle-of-attack variations about $(\overline{P},\overline{Y})$ due to non-zero cross-flows. For example, if $\underline{U}_T = (U,V,W)$, then

$$P' = \tan^{-1}\left(\frac{W}{U}\right)$$

and

$$Y' = \tan^{-1}\left(\frac{V}{U}\right)$$

are small corrections to the mean angles of attack $(\overline{P},\overline{Y})$ for each rotor. A two-step iterative process results in ±1% accuracy for individual values if P' and Y' are less than 10° (although larger values occasionally occur, output from the high frequency probes will be unreliable at these times, hence there is little interest in spectral processing of these current meter records). The first step uses $g(\overline{P},\overline{Y})$ to correct each rotor output and calculate U, V and W, which are used to calculate P' and Y' as defined above. If P' and Y' are small angles, the arc angle $\varepsilon \equiv \tan^{-1}(Y'/P')$ can be used to interpolate on the response surface of a given rotor between

$$FP(\beta') \equiv g_P(\overline{P} + \beta',\overline{Y}) - g_P(\overline{P},\overline{Y})$$

and

$$FY(\beta') = g_Y(\overline{P},\overline{Y} + \beta') - g_Y(\overline{P},\overline{Y}) ,$$

where $$(\beta')^2 = (P')^2 + (Y')^2$$ (as shown in Figure 25),

giving the correction

$$\Delta g \;=\; FP(\beta') + \frac{2\varepsilon}{\pi}\,(FY(\beta') - FP(\beta'))\;.$$

The corrected response $(g(\overline{P},\overline{Y}) + \Delta g)$ is calculated in this way for each rotor, then used to re-calculate U, V and W.

2.7 Pressure gauge

Pressure is sensed with a Computer Instrument Corporation Bourdon tube transducer, mounted in a separate pressure case just behind the main instrument package. Calibration against a dead-weight tester, before the cruise is shown in Figure 26. Manufacturer specifications claim a static error of ±0.6% of full-scale pressure, or ∿ ±4 dbar for the 1000-psi gauge, but observation of pressure difference at the surface before and after a dive indicate that differences of the order of ±2 d bar were typical of absolute error. A noise level equivalent to ±0.2 dbar arose from electrical pickup inside the submersible, where the pressure signal is displayed as part of the pilot control system.

2.8 Accelerometers

Three Sundstrand Model QA 1000 accelerometers were mounted in an orthogonal jig within the main pressure case 0.35 m behind the high-frequency sensors, all of which are affected to varying degrees by vehicle vibrations. Output from the accelerometers provides information both on low frequency (pitch and roll) attitude changes of the submersible and on high frequency accelerations due to vibration. Manufacturer specifications claim resolution as an accelerometer of better than $((1 \times 10^{-6})g)$ for frequencies to 300 Hz. Thus the accelerometer output was low-pass filtered with a half-power point of 100 Hz before sampling at 250 Hz.

For calibration, an accelerometer was first used to level a machined platform, then mounted on a 5 inch sine bar: output from the accelerometer was recorded as a function of angle α from level as the sine bar was rested on different gage blocks. Figure 27 shows output voltage to be a highly linear function of sin α for five accelerometers (the three used are underlined). The curves are shifted relative to each other for clarity and zero for each accelerometer is marked by a horizontal bar at lower left.

Calibration coefficients are listed below for the PITCH (accelerometer axis parallel to axis of main pressure case and high-frequency sensors), ROLL (accelerometer axis perpendicular to PITCH axis in horizontal plane) and VERTICAL (accelerometer axis perpendicular to PITCH axis in vertical plane) sensors, where the output voltage V is given by:

$$V = V_0 + G\left(\sin\alpha + \frac{\ddot{x}}{g}\right)$$

V_0 = volts out at $\alpha = 0$, $\ddot{x} = 0$

α = angle of inclination from horizontal

$\ddot{x}$ = acceleration

g = acceleration due to gravity, taken as 980 cm s^{-2}

TABLE 5: Accelerometer calibration constants

	PITCH (210)	ROLL (209)	VERT (367)
V_0 (volts)	-0.0531	+0.0007	-0.0035
G(volts/g)	8.546	8.253	7.805

The low-frequency information provided by the PITCH and ROLL accelerometers is interpreted as true roll and pitch. However, without a full inertial navigation system, there is no way to distinguish, for example, between true rolling motion and low-frequency yawing motion: thus the designations PITCH and ROLL should be interpreted loosely, and the low-frequency information used only as a qualitative indication of submersible motions.

The primary use of the three accelerometers is to measure vibrations parallel to the axes of the high-frequency velocity components measured by the hot film and airfoil sensors. Bit size in acceleration of $((3.052 \times 10^{-4}\ g)/G)\mathrm{cm\ s^{-2}}$, (for example, $0.036\ \mathrm{cm\ s^{-2}}$ for the ROLL accelerometer) is not a limiting factor for this measurement. Typical accelerometer spectra are shown in Figure 28. The fundamental vibration frequency (1 at 10.8 Hz) is that of the propellers used to drive the submersible, and shows up much more strongly in ROLL, the cross-submersible axis, than in PITCH or VERT. The strut can't be further strengthened in this direction because the attachment points to the submersible are fixed and not very far apart. Various harmonics of the fundamental are noted in Figure 28. Fortunately for our purpose of measuring a broad-band turbulence spectrum, the vibration peaks observed, with the exception of the 10.8 Hz peak in ROLL, are quite narrow: frequency resolution in Figure 28 is $\sim$ 0.5 Hz and most of the peaks are only one point wide. Exceptions are the broad-band vibrations in the PITCH (fore-and-aft) direction above about 30 Hz.

"Velocity" spectra can be formed by dividing the accelerometer spectra by $(2\pi f)^2$, and Figure 29 shows such a derived axial velocity spectrum (heavy solid line) plotted over a set of 'universal' curves, the velocity spectra expected for the noted values of turbulent kinetic energy dissipation ε ($\mathrm{cm^2\ s^{-3}}$) if the turbulence satisfies Kolmogoroff's assumption of isotropy and universality. Positions of the maxima of the dissipation spectra for these values of ε are marked as solid circles along the locus of the dissipation maximum. It is clear that the system should allow measurement of ε values down to $\sim 10^{-5}\ \mathrm{cm^2\ s^{-3}}$, provided that no large amplification of vibrations occurs over the approximately 25 cm separating accelerometers and high-frequency probes. Also shown in this figure is a shaded area corresponding to a range of "noise" spectra of axial velocity from a hot-film velocity sensor operated on a depth-controlled towed body (Gargett, 1976). The improvement in effective velocity noise level offered by the submersible system is apparent.

3. Measurements

Knight Inlet is one of the narrow steep-walled fjord-type inlets which indent the mainland coast of British Columbia. Most of the fresh water input to the surface layers comes from the Klinaklini and Franklin Rivers at the head of the inlet. As shown in Figure 30, the inlet is divided into two basins, an outer shallow one and a deeper inner one, by a sill rising within 63 m of the water surface. Strong surface bands of alternately smooth and ruffled water were identified as due to internal wave motions as early as 1954 (Pickard, 1954). Recent observations by Farmer and Smith (1980) have demonstrated that a large group of internal waves (first mode in the winter and second mode in summer) is generated by tidal ebb flow over the submarine sill across the inlet, and propagates up-inlet on the flood tide. Freeland and Farmer (1980) demonstrate that these wave trains carry sufficient energy to dominate vertical mixing process in the inlet; thus it seemed of interest to obtain direct measurements of the dissipative scales of turbulence through such a wave train.

Measurements through the internal wave train at various distances from the sill were obtained on Nov. 13 through 19, as the tidal range decreased from 3.3 m to 2.0 m. High wind conditions prevented measurements on Nov. 18. Figures 31(a) and 31(b) show rough dive tracks for each day, with launch and recovery positions marked by solid and open circles respectively. Since the submersible does not carry positioning gear, the courses shown are those of the tracking launch, as taken from the ship's radar. However, the launch generally follows the submersible quite closely, particularly when, as here, there exists some chance of hitting the sides of the inlet if the submersible were allowed to get too far off course. Dives on Nov. 13 and 14 used the hot-film velocity probe TSI-8214, later found to have an unstable calibration. The remaining dives through the wave train (Nov. 15 through 19) used the stable probe V30. On all dives except Nov. 19, we achieved at least one and often two passes through the turbulent wave train. However, transects down-inlet, i.e. against the direction of propagation of the wave train were often unsuccessful because very strong downwelling velocities at the leading edge would push the submersible down, much like a helpless Swallow float following the rapid plunge of a near-surface streamline. Thus the most successful passes through the wave train were from behind its leading edge, in the direction of propagation.

Figure 32 shows the complete set of variables measured by the submersible system during such a transect on Nov. 16. This record contains a number of features typical of submersible operations in general, as well as those characteristic of measurements within the wave train.

The pressure record far back in the wave train (left of Figure 32) shows the slight and relatively gentle changes in descent rates which are introduced by pilot adjustment of submersible wing angle. The step-like changes in pressure further forward in the wave train, and the steep descent rate immediately in front of the leading edge (right of Figure 32) are all effects of strong vertical velocity fields acting on the large plane surface of the wings. At the leading edge of the wave train, this effect was often so large that, as in this case, even a full upward angle on the wings was not sufficient to stop the steady descent of the submersible.

The accelerometer records (bottom three traces) show other effects of the water motions within the wave train. To the left of Figure 32, all three traces are characteristic of general submersible operations. The submersible has a relatively regular rolling motion with 5 to 10 second period, while pitching motions are typically more irregular with longer periods. These low frequency pitch and roll motions are noticeably larger through the front third of the wave train, as the submersible is moved around by much stronger wave and turbulent velocity fields. Because the submersible is moved by velocity fields with scales comparable to itself, we cannot measure the energy-containing range of the velocity field in the absence of complete, accurate and rapid information on the submersible's position. At higher frequencies, however, there is no noticeable change in accelerometer signals between the rear and the front of the wave train.

The upper three traces in Figure 32 are respectively temperature, salinity, and an estimate of vertical temperature gradient from the temperature difference over 0.8 m. Passage through the leading edge of the wave train is marked by a narrow spike of very cold and fresh water, as the surface layer of the inlet is swept downward by the same strong vertical velocities which push the submersible down in this region. In these traces, passage through an internal wave crest is marked by appearance of warmer saltier water, as the submersible moves into water characteristic of the lower layers of the inlet. Such appearances are marked a - b - c - d in Figure 32, and serve to locate the high frequency turbulent fields within the framework of the internal wave train. Defining the z-axis as positive upward, the temperature gradient in the upper layers of Knight Inlet is normally negative. Our gradient estimate is normally negative (left of Figure 32), but toward the front of the wave train, it shows an increasing incidence of positive values, indicating overturning on at least the 0.8 m vertical scale of the measurement.

The high frequency temperature (T') and velocity (u,v,w) traces include frequencies from 1 to 100 Hz, corresponding roughly to horizontal scales of 1 metre to 1 centimetre. All three velocity traces have similar character, although different effective noise levels due to vibration-induced velocities. As expected, the cross-submersible airfoil channel (v) has the worst such noise level. It is clear from these analog records that the turbulence in the wave train is confined to the upper layer of Knight Inlet; passage of the submersible into the warmer saltier lower layer is associated with a return to noise level on all three velocity channels.

The mean forward speed of the submersible as measured by the heated platinum film (U_{PV}) generally agrees with that measured by the triplet of rotor current meters (U_{RCM}) to within ±2 cm s^{-1}, adequate agreement considering that the two instruments are separated by ∿ 0.28 m vertically and ∿ 0.33 m horizontally. Rotor-derived measurements of low frequency cross-flows (V and W) have been combined with mean forward speed to produce Θ, the instantaneous angle of attack of the mean flow relative to the axis of the high-frequency probes. This is an essential parameter to monitor, because performance of both heated-film and airfoil probes degrades for angles-of-attack larger than ∿ 10°. Except in a few limited portions of the record near the front of the wave train, Θ is certainly less than 10° and routinely less than 5° for typical submersible operation.

We also attempted some measurements on the downstream side of the sill on ebb tide, when large internal hydraulic disturbances tied to the sill produce a near-surface mixing layer downstream (Smith and Farmer, 1980). Tracks for November 20 and 21 are shown in Figure 31(c). These observations were less successful than those through the internal wave train, partly because of our reluctance to approach too closely either to the strong flows associated with the internal hydraulic jump in the waters over the sill or to the sides of the sill itself, and partly because of timing, which had us diving in this location at a time of slackening ebb. However, on one of the closest approaches to the sill on November 21, we encountered strong continuous turbulence in the near-surface layer. Figure 33 shows records obtained in this region as the submersible travels originally towards the sill, then turns through 180° near the middle of the record to move away from the sill over the last half of the record. At the beginning of the record, high frequency velocity and temperature signals are very weak as the submersible passes down and back up through a strong temperature and salinity gradient separating the warmer saltier lower layer of the inlet from cooler fresher near-surface waters. As the submersible moves closer to the sill within the upper layer, continuous turbulence is encountered, but it apparently disappears abruptly about halfway through the submersible's turn. This is probably the result of a slight depth change, as the submersible sinks below the turbulent upper layer during the turning manoeuvre: continuous turbulent signals reappear abruptly as the submersible rises slightly in the water column on its new course away from the sill.

4. Acknowledgements

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5. Appendix: Tables

TABLE A1: Probe list, all dives; Tapes 815-844 are Knight Inlet data.

TAPE NUMBERS	u	w	v	T'	C	TA	TB	RCM A	RCM B	RCM C
802-804	TSI-8214	11A	12A	TS-T1	1	1	26	1	5	3
805-810										2
811-814		15A	10A							
815-817A						2				
919-822	V30									
823-844						22				

TABLE A2: Data Channel numbers and sample rates

SCRIBE CH. NO.			SIGNAL	SAMPLE RATE (Hz)	HP CH. NO.
			Differential Inputs:		
0	PV	=	Platinum Velocity, high-pass (u)	1000	0
1	TPV	=	Platinum Velocity, low-pass	25	1
2	PT	=	Platinum Temperature, high-pass (T')	1000	2
3	C	=	Conductivity	250	3
4	TA	=	Thermistor A (in conductivity cell)	250	4
5	TB	=	Thermistor B	250	5
6			Ground	25	6
7			Spare	25	7
8			Spare	25	8
			Single-ended Inputs:		
10	S_1	=	Cross-Slow velocity, Channel 1 (w)	250	16
11	S_2	=	Cross-Slow velocity, Channel 2 (v)	250	17
12	P	=	Pitch accelerometer	250	18
13	R	=	Roll accelerometer	250	19
14	V	=	Vertical accelerometer	250	20
15	IP	=	Pitch accelerometer inside sphere	250	21
16	IR	=	Roll accelerometer inside sphere	250	22
17	D	=	Pressure	25	23
18			Ground	25	24
19			+ Reference	25	25
1A			- Reference	25	26
1B			Spare	25	27
1C			Spare	25	28
			Digital Inputs:		
20	A	=	Rotor A	25	32
21	B	=	Rotor B	25	33
22	C	=	Rotor C front view	25	34
30			Spare	25	35

A/D CONVERTER:

$$\text{Bit size} = \frac{\pm 10 \text{ volts}}{\pm 2^{15}} = 3.05176 \times 10^{-4} \text{ v.}$$

TABLE A3: PISCES Dive Information, Knight Inlet, B.C., November 1978.

DIVE NO.	DAY-MO	TAPE	FILE	CASS NO.	RECORD NO.	LAUNCH RECOVER LAT(N)	LONG(W)	TIME IN WATER (HR)
705	13-11	812	1	12	1-5119	50° 41.9′	125° 45.6′	3.5
				13	5120-5241			
			2	13	1-5111			
				14	5112-8735			
		813	1	14	1-1297			
				17	1298-6123			
			2	17	1-617			
				18	618-5775			
		814	1	19	1-5300			
				21	5301-11214	50 41.9	125 46.0	
706	14-11	815	1	31	1-5401	50 41.5	125 49.4	3.5
			2	33	1-5506			
		816	1	34	1-5544			
			2	35	1-5510			
		817	1	36	1-5468			
			2	37	1-936			
			3	37	1-4431			
		817A	1	38	1-5724	50 41.2	125 49.6	
707	15-11	819	1	11	1-5485	50 41.3	125 50.4	3.8
			2	10	1-5350			
			3	12	1-1524			
		820	1	12	1-3616			
				13	3617-8794			
			2	13	1-2625			
				14	2626-5361			
		821	1	14	1-121			
				17	122-5460			
				18	5461-10537			
		822	1	19	1-5628			
			2	21	1-667			
			3	22	1-5077	50 41.3	125 50.4	
708	16-11	823	1	31	1-5594	50 41.8	125 45.8	3.6
			2	30	1-5376			
		824	1	32	1-5506			
			2	33	1-5476			
		825	1	34	1-5808			
			2	35	1-5506			
		826	1	36	1-562			
			2	36	1-5161			
			3	37	1-5409			
			4	38	1-701	50 41.8	125 48.2	

DIVE NO.	DAY-MO	TAPE	FILE	CASS NO.	RECORD NO.	LAUNCH RECOVER LAT(N)	LONG(W)	TIME IN WATER (HR)
709	17-11	827	1	11	1-5779	50° 42.3′	125° 42.3′	3.5
			2	12	1-5140			
		828	1	13	1-5867			
			2	14	1-4909			
		829	1	18	1-5346			
			2	19	1-5535			
		830	1	21	1-6056			
			2	22	1-5384			
		830A	1	39	1-3540	50 42.6	125 45.5	
710	19-11	831	1	30	1-5594	50 40.9	125 53.3	3.4
			2	31	1-5384			
		832	1	32	1-5531			
			2	33	1-5493			
		833	1	34	1-5808			
			2	35	1-5473			
			3	36	1-256	50 40.3	125 55.5	
711	20-11	834	1	11	1-5749	50 43.0	126 01.5	3.3
			2	12	1-5174			
		835	1	13	1-5523			
			2	13/14	1-5325			
		836	1	18	1-5388			
			2	19	1-5581			
		836A	1	21	1-6000	50 40.4	126 02.3	
712	21-11	837	1	30	1-5573	50 40.3	126 02.5	3.3
			2	31	1-5401			
		838	1	32	1-5552			
			2	33	1-5489			
		839	1	34	1-5838			
			2	35	1-5535			
		840	1	36	1-5749			
			2	37	1-540			
			3	38	1-558	50 40.2	126 03.5	

6. References

Allen, H.J. and E.W. Perkins, 1952: A study of effects of flow over slender inclined bodies of revolution. National Advisory Council for Aeronautics Report. No. 1048.

Eckman, D.P., 1950: Industrial Instrumentation. John Wiley and Sons, N.Y.

Evans, D.J., 1963: An instrument for the measurement of ocean turbulence. Pac. Naval Lab. Tech. Memo. 63-8, 20 pp., Defence Research Establishment Pacific, FMO, Esquimalt, B.C., Canada.

Fabula, A., 1968: The dynamic response of towed thermometers. J. Fluid Mech. *34*, 449-464.

Farmer, D.M. and J.D. Smith, 1978: Non-linear internal waves in a fjord. *Hydrodynamics of Estuaries and Fjords.* Ed. J. Nihoul, Elsevier, Amsterdam, 546 pp.

Farmer, D.M. and J.D. Smith, 1980: Generation of lee waves over the sill in Knight Inlet. *Fjord Oceanography*, ed. H.J. Freeland, D.M. Farmer and C.D. Levings, Plenum Press, New York, 702 pp.

Freeland, H.J. and D.L. Farmer, 1980: The energy budget and the circulation of a deep, strongly stratified inlet. Submitted to Canadian J. of Fisheries and Aquatic Sciences.

Galloway, J.L. and R.C. Teichrob, 1979: SCRIBE-Data acquisition in a submersible. Proceedings of OCEANS, September, 1979. IEEE.

Gargett, A.E., 1976: Microstructure and finestructure in an upper ocean frontal regime. J. Geophys. Res., *83*, 5123-5134.

Grant, H.L., R.W. Stewart and A. Moilliett, 1962: Turbulence spectra from a tidal channel. J. Fluid Mech. *12*, 241-268.

Grant, H.L., B.A. Hughes, W.M. Vogel, and A. Moilliett, 1968: The spectrum of temperature fluctuations in turbulent flow. J. Fluid Mech., *34*, 423-442.

Lueck, R.G., 1979: Heated anemometry and thermometry in water. PhD Thesis, Dept. of Oceanography, Univ. of British Columbia, Vancouver, B.C., 157 pp.

Nasmyth, P.W., 1970: Oceanic turbulence. PhD Thesis, Institute of Oceanography, University of British Columbia, Vancouver, B.C., Canada.

Osborn, T.R. and W.R. Crawford, 1977: Turbulent velocity measurements with an airfoil probe. IOUBC Man. Report No. 31, 39 pp. Institute of Oceanography, University of British Columbia, Vancouver, B.C., Canada.

Pickard, G.L., 1954: Oceanography of British Columbia mainland inlets. III Internal waves. Fish. Res. Bd. Canada, Pacific Prog. Rept., No. 97.

Ribe, R.L. and J.G. Howe, 1967: An empirical equation relating sea water salinity, temperature, pressure, and electrical conductivity. Unpublished report, Oceanographic Instrumentation Center, Naval Oceanographic Office, U.S.A.

Smith, J.D., 1974: Turbulent structure of the surface boundary layer in an ice-covered ocean. Rapp. P.-v. Réun. Cons. int. Explor. Mer., *167*, 53-65.

Smith, J.D. and D.M. Farmer, 1980: Mixing induced by internal hydraulic disturbances in the vicinity of sills. Fjord Oceanography, ed. H.J. Freeland, D.M. Farmer and C.D. Levings, Plenum Press, New York, 702 pp.

7. Figures

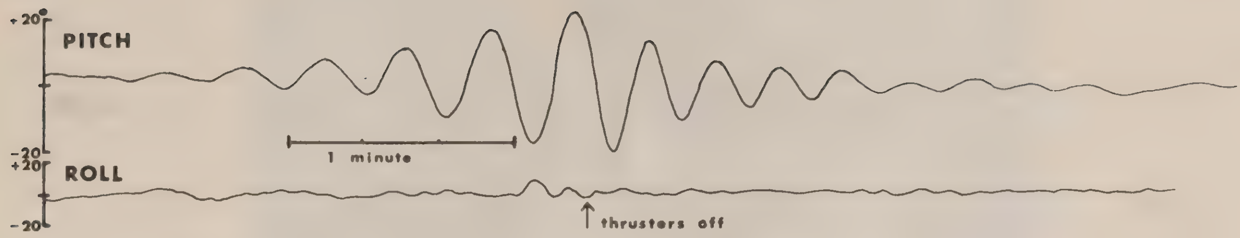


Figure 1: Records from pitch (fore-and-aft) and roll (side-to-side) accelerometers document the rapid growth of a severe pitch instability, which made PISCES IV unsuitable for mid-water running before it was fitted with stabilizing wings. The submersible's driving thrusters were turned on full ahead at the beginning of this record, and off at the position noted.

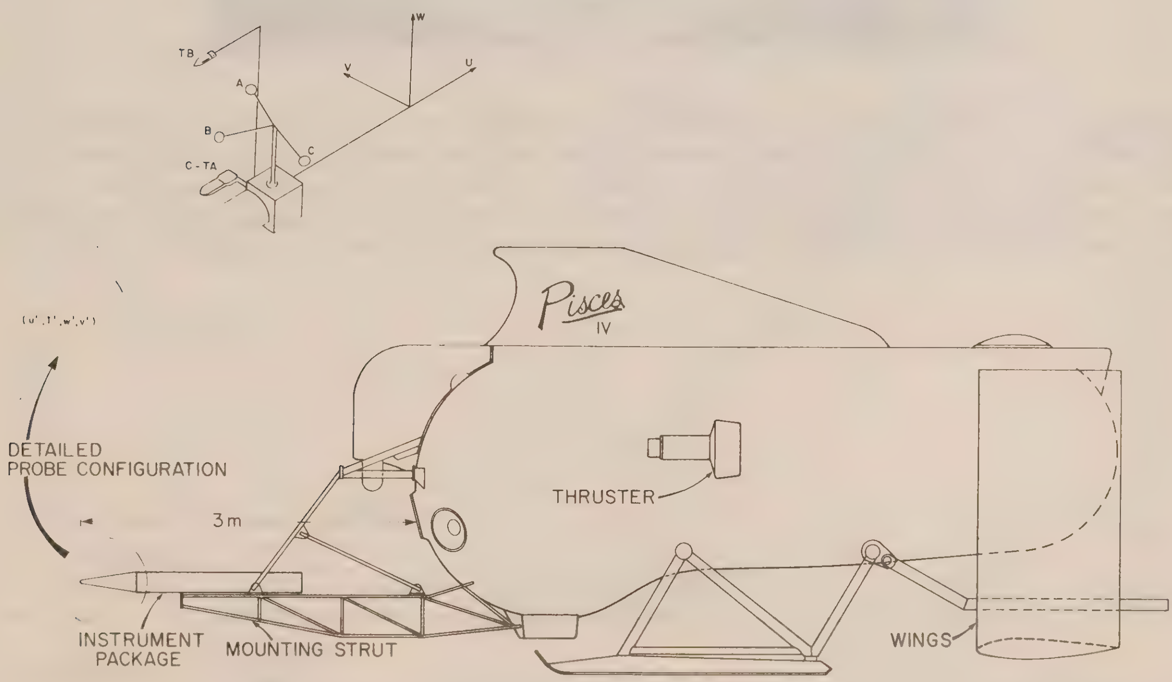


Figure 2: A side view of PISCES IV showing the stabilizing wings, and the position of the instrument package detailed in the inset at top left. All velocities are referred to the submersible-defined co-ordinate system shown here.

Figure 3: A rear view of PISCES IV, showing the three-bladed propellors of the thrusters which drive the submersible and the stabilizing wings necessary for turbulence research with this vehicle. The black rectangle at the trailing edge of the right-hand upright wing section is a trim tab, hydraulically controlled from within the submersible to provide stability in yaw.

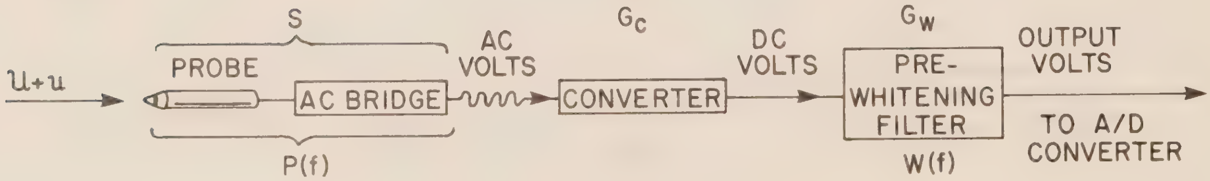


Figure 4: Block diagram of the electronics associated with the hot-film sensor for axial speed u. For discussion, see Section 2.1.

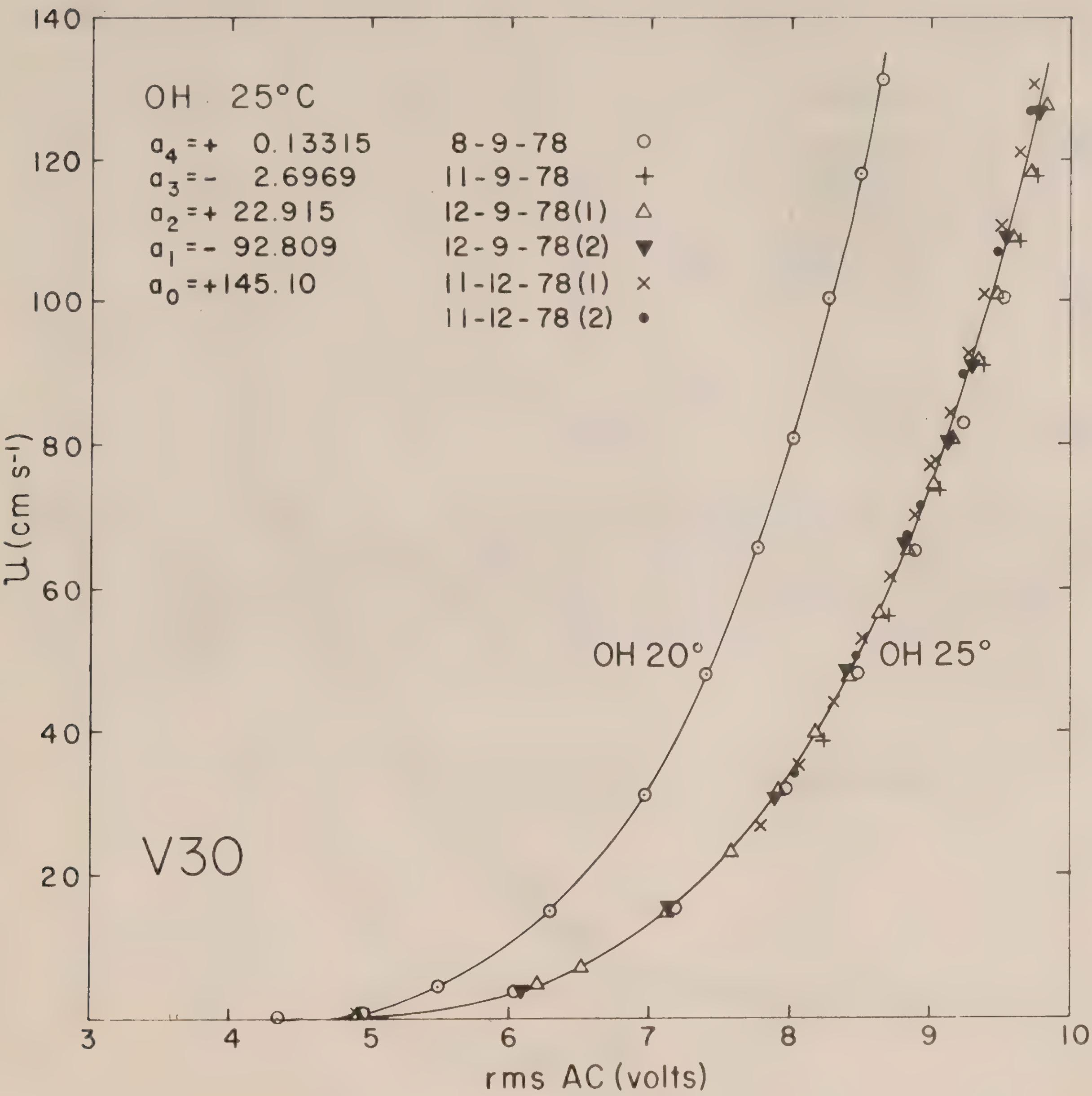


Figure 5(a): Steady calibration of hot-film probe V30 for two different overheat values. Repeated calibrations at overheat 25°C were taken over a three-month period during which V30 was operated in the field for approximately 20 hours. Coefficients a_i, i = 0,4 are for a fourth order fit to the combined calibration data, i.e. $U = \sum_{i=0}^{4} a_i (\text{rms AC})^i$.

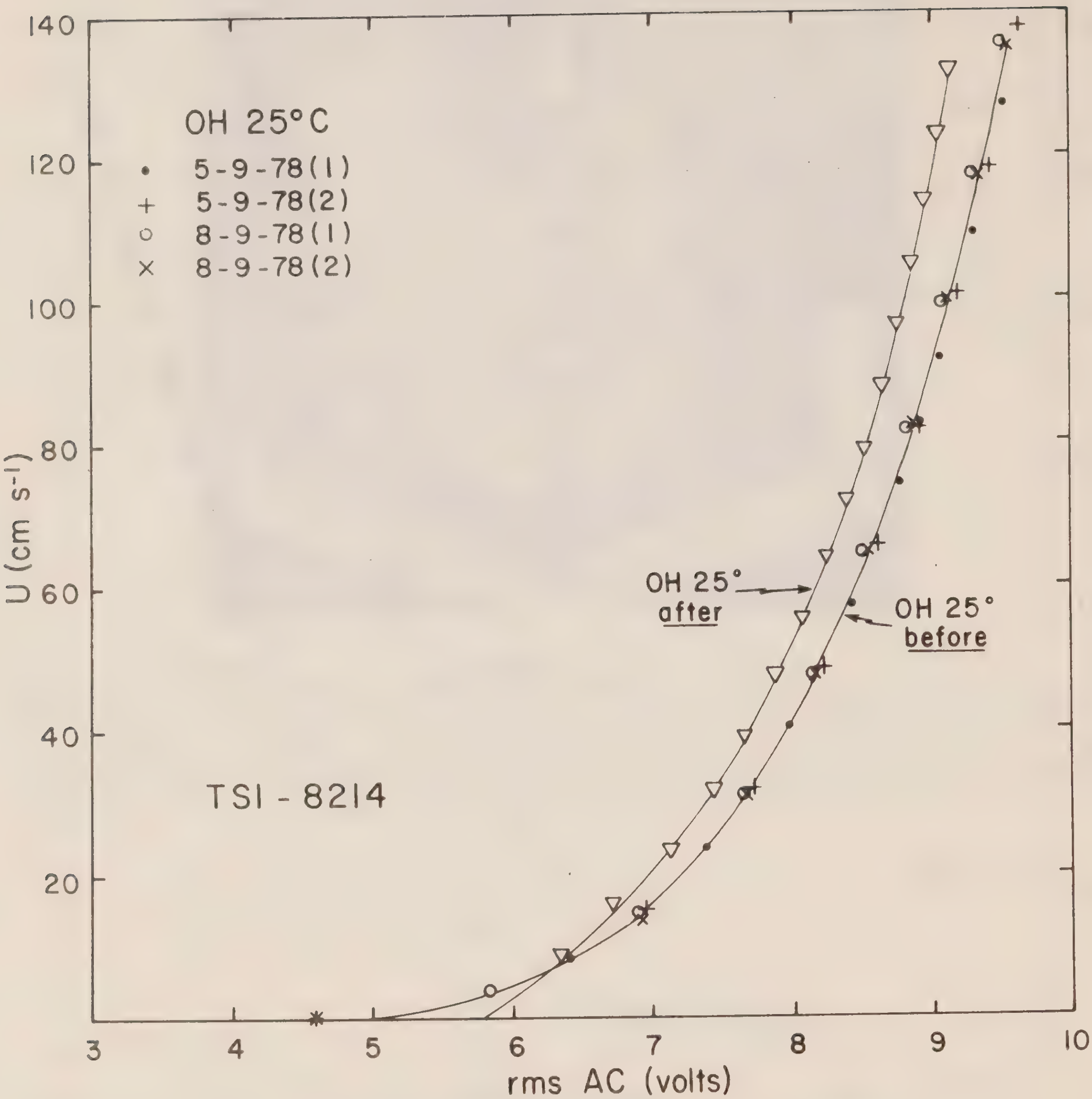


Figure 5(b): Steady calibration data of commercial hot-film probe TSI-8214 (Thermo-Systems Model 1230W). Calibrations run before using this probe in the field are repeatable, but differ considerably from a calibration after some 24 hours operation in salt water.

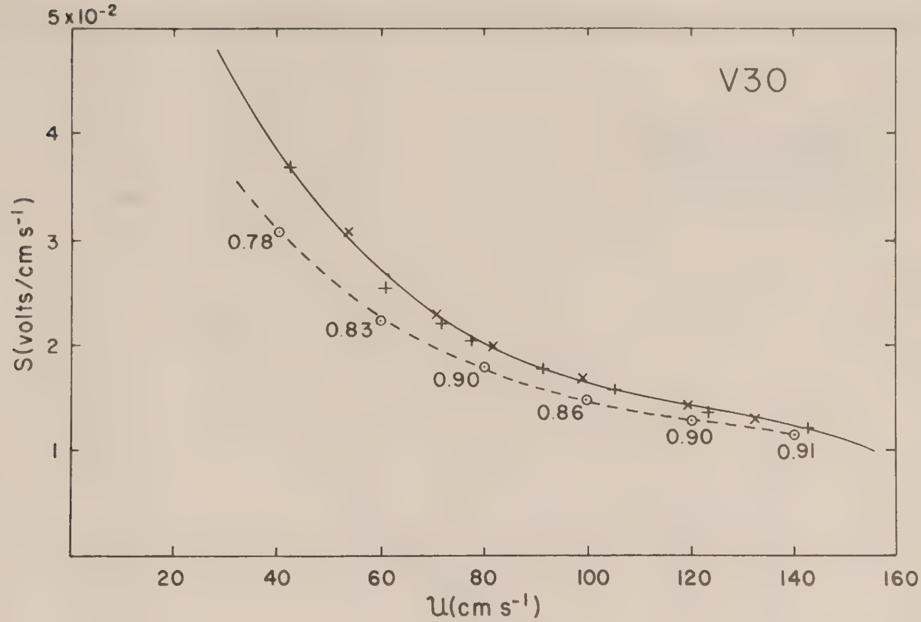


Figure 6(a): Sensitivity S of the probe/bridge system as a function of mean speed U for probe V30. The solid curve is a cubic least-squares fit to the set of points from dynamic calibrations at 30 Hz (+) and 50 Hz (x). The static sensitivities (⊙) lie consistently below this curve. Around the 100 cm s^{-1} speed of submersible operations, the appropriate ratio value of static to dynamic sensitivities is ∿ 0.9.

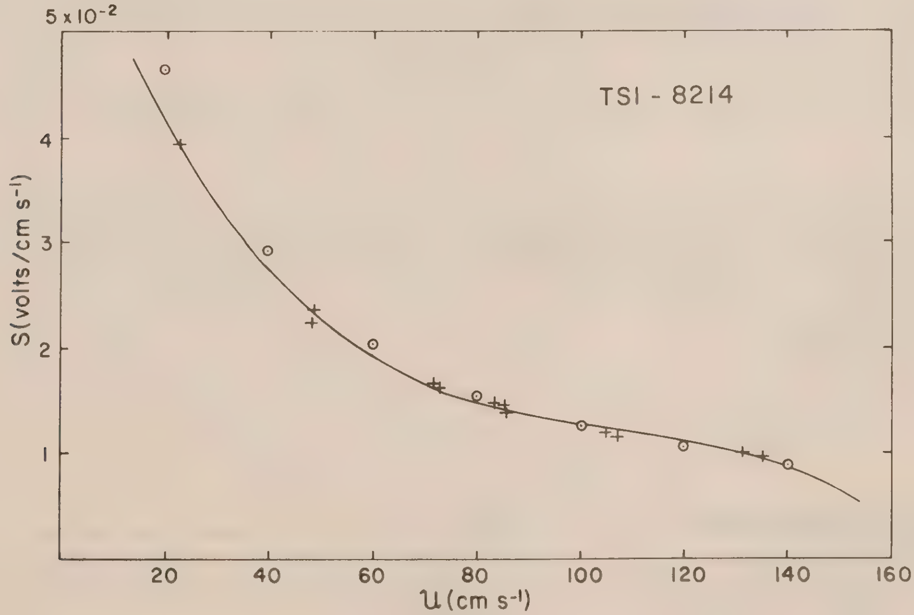


Figure 6(b): Sensitivity S of the probe/bridge system as a function of mean speed U for probe TSI-8214. Static sensitivities (⊙) for this probe equal dynamic sensitivities measured at 30 Hz (+).

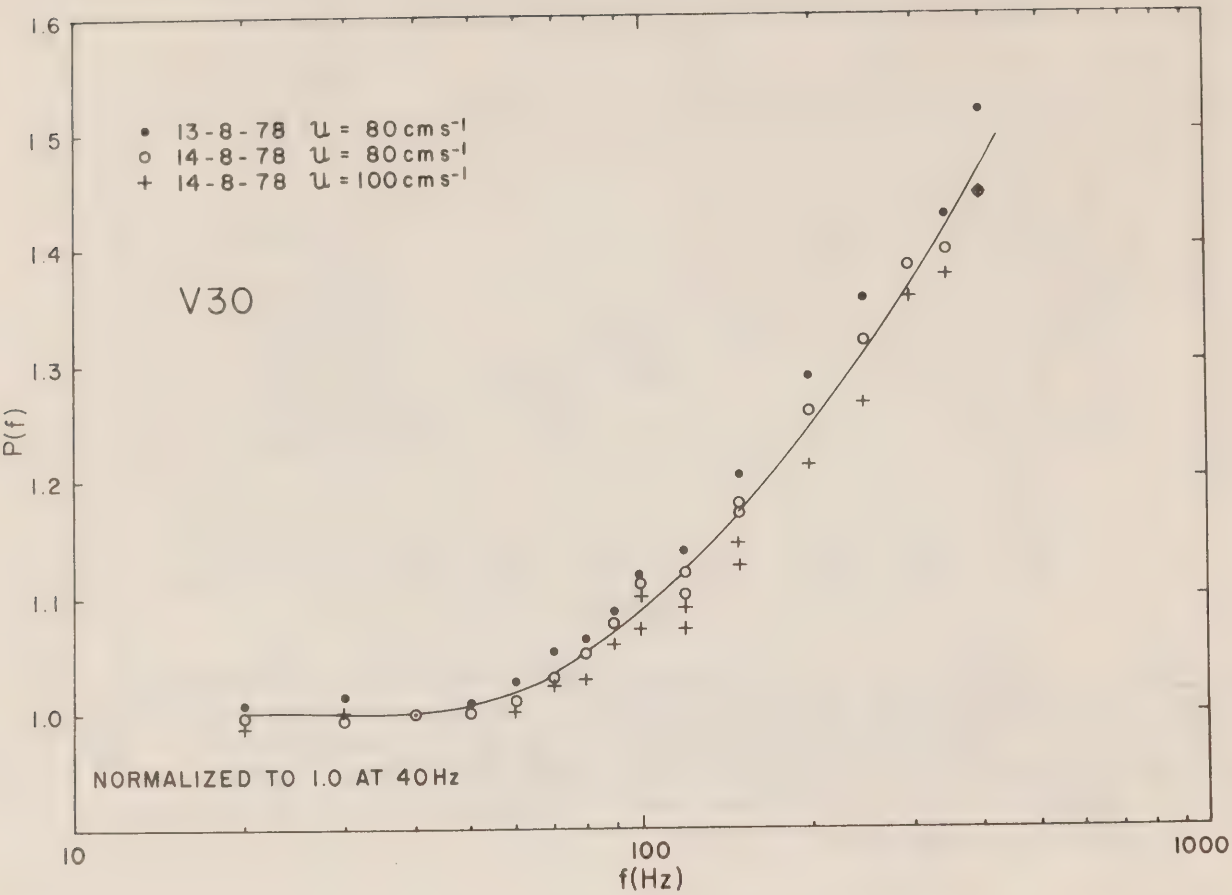


Figure 7(a): Probe/bridge response as a function of frequency for V30, normalized to 1.0 at 40 Hz.

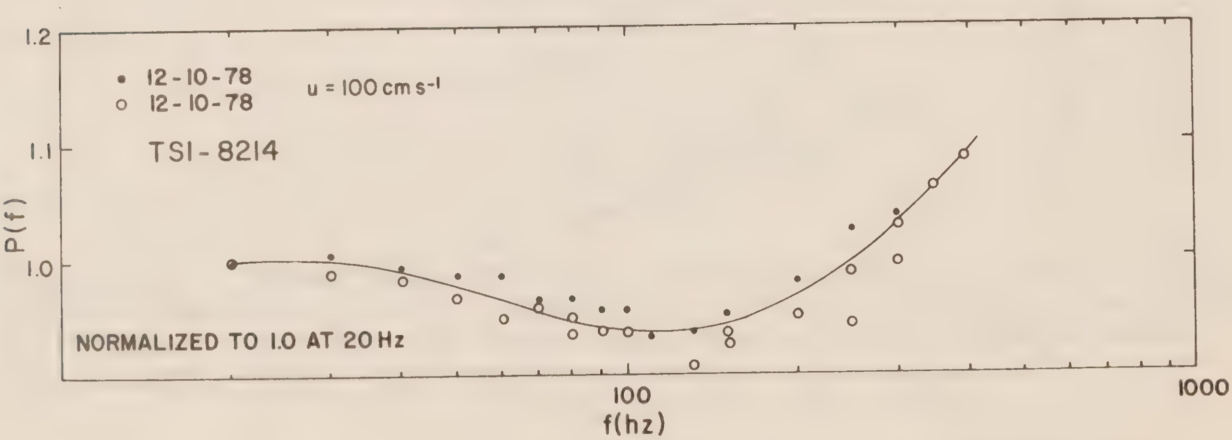


Figure 7(b): Probe/bridge response as a function of frequency for TSI-8214, normalized to 1.0 at 20 Hz.

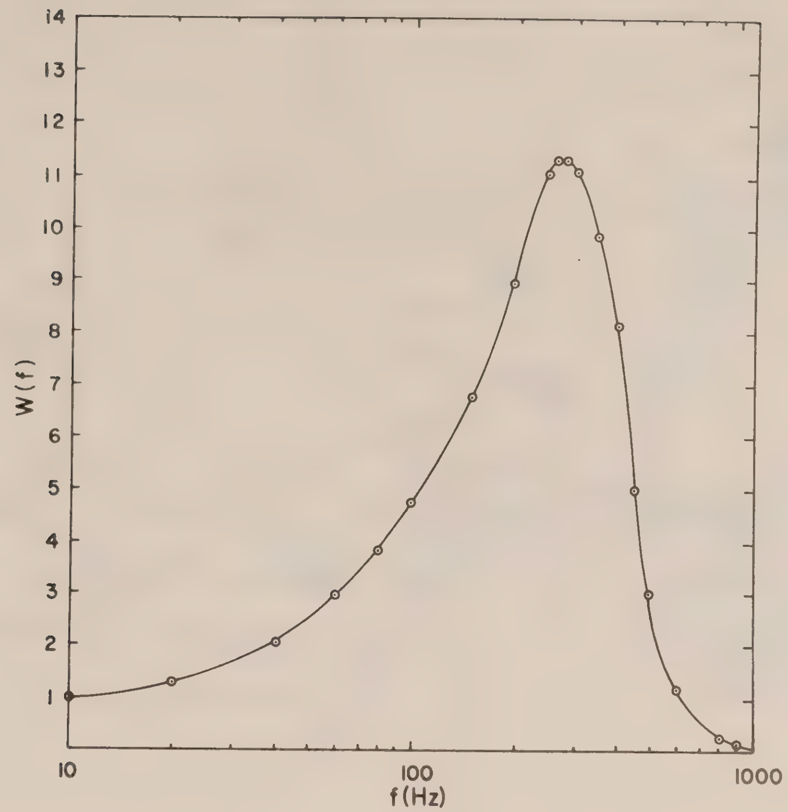


Figure 8: Response of pre-whitening filter as a function of frequency, normalized to 1.0 at 0 Hz.

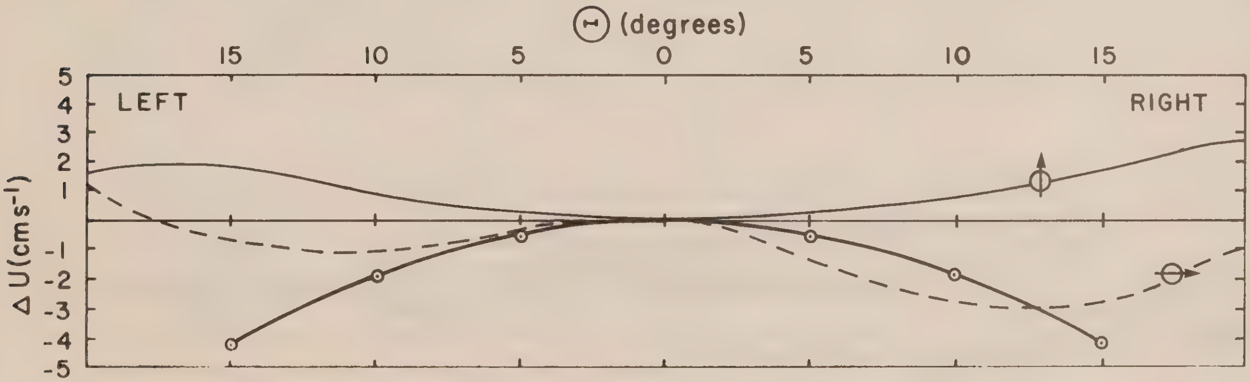


Figure 9: Change in steady output of V30 as the probe is rotated through an angle Θ from the mean flow direction. If the film were exactly radially symmetric, there would be no difference between the response when the probe is rotated by 90°, i.e. from a position in which the electrical leads are vertical ( ) to one in which they are horizontal ( ): small asymmetries in probe geometry result in slightly different curves. An ideal velocity component sensor would have a cosine response (heavy line).

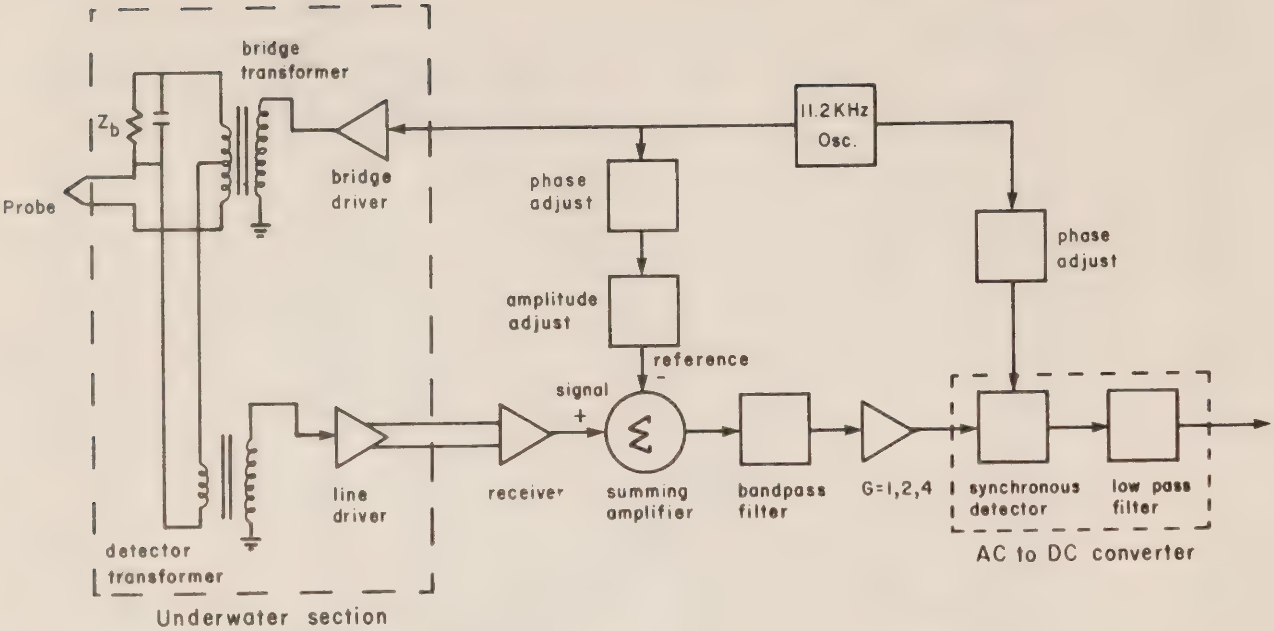


Figure 10(a): Schematic diagram of AC bridge for measurement of high-frequency temperature with an unheated platinum-film probe.

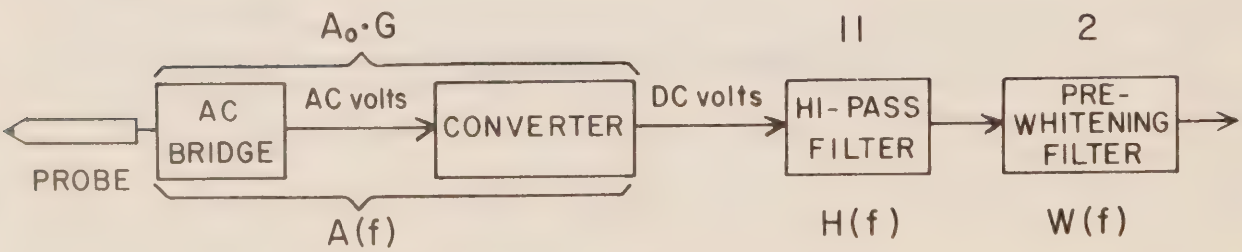


Figure 10(b): Block diagram of electronics associated with the cold-film sensor for temperature T'. For discussion, see Section 2.2.

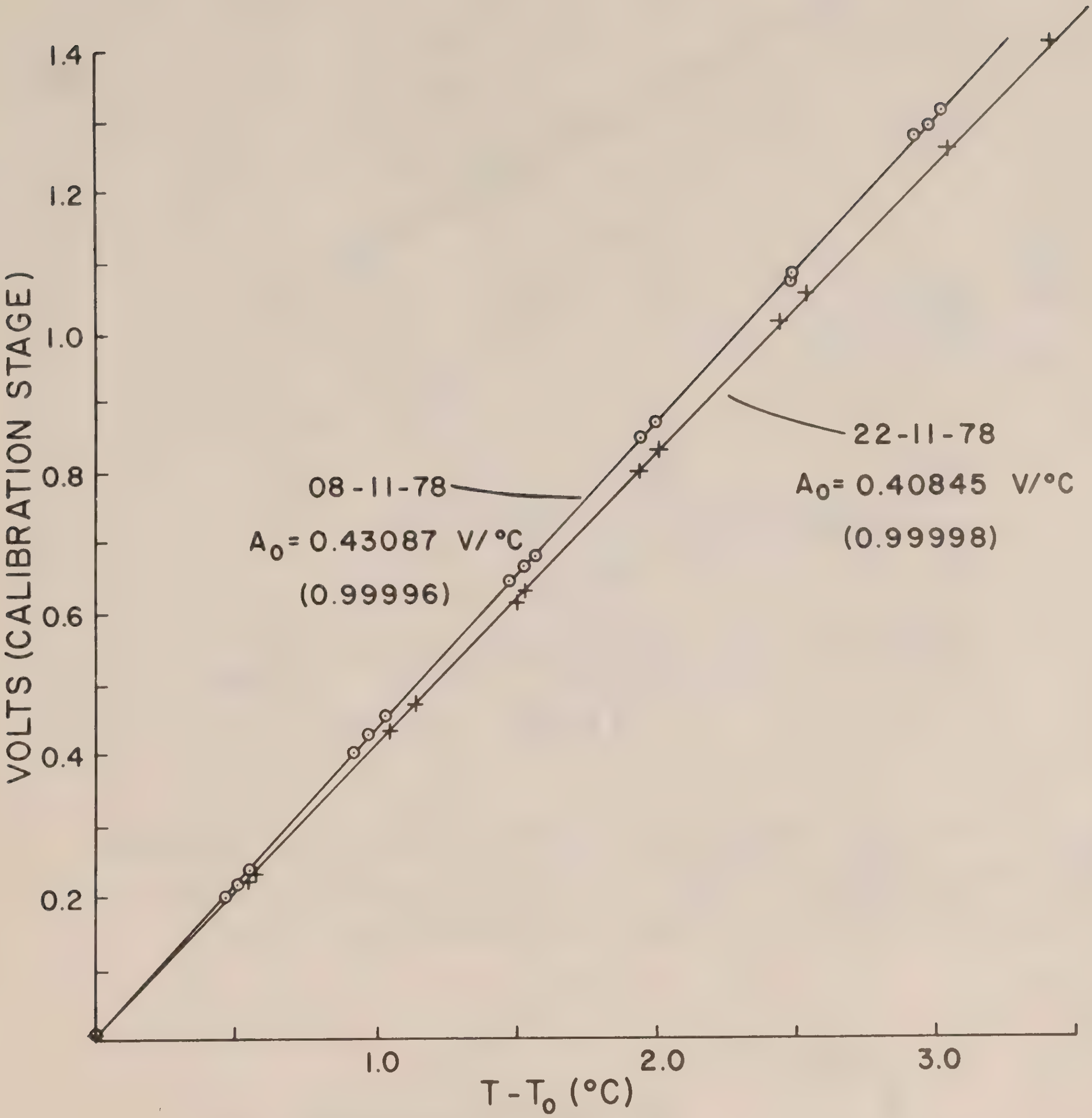


Figure 11: Two separate sensitivity calibrations of TS-T1 output voltage as a function of mean water temperature.

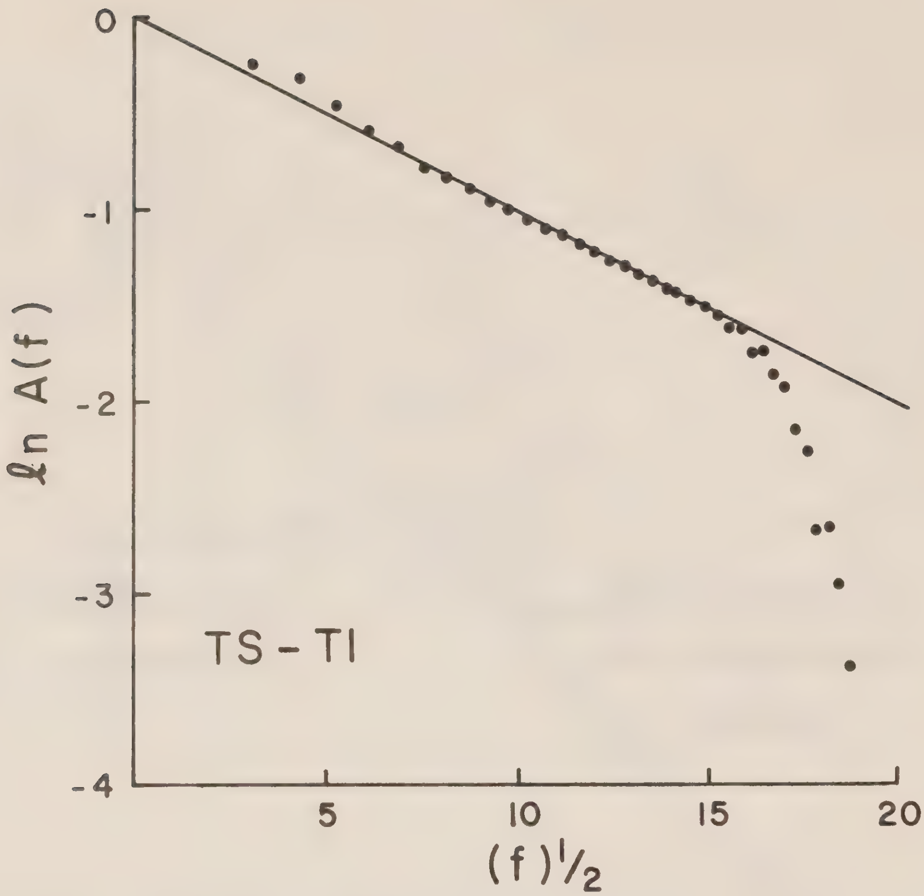
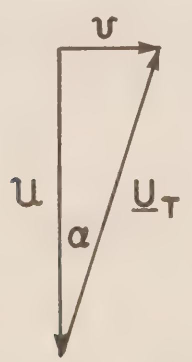


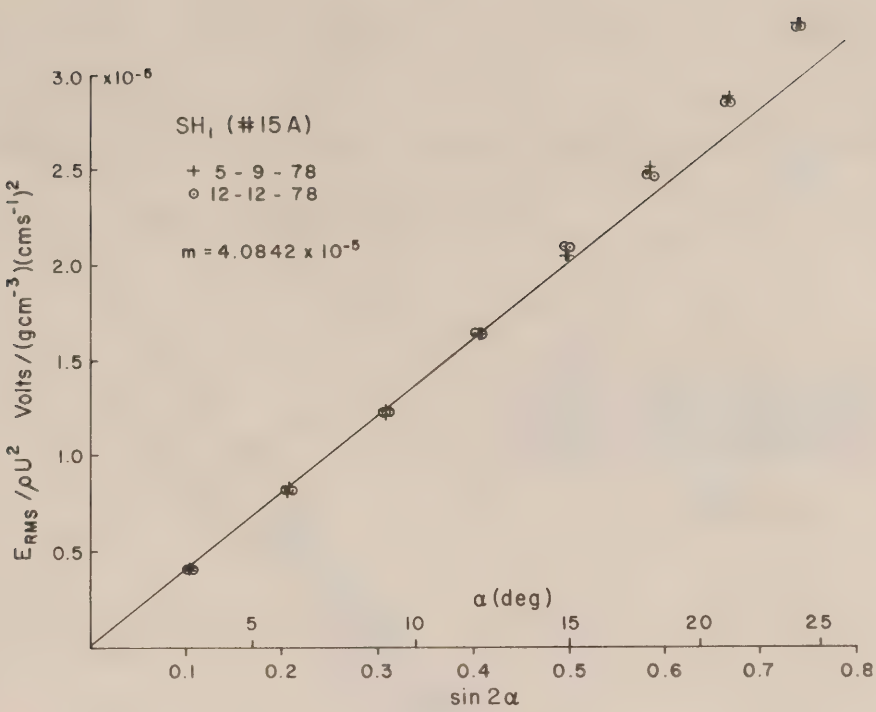
Figure 12: The slope of a straight line fit to ln A(f) as a function of $(f)^{\frac{1}{2}}$ yields the parameter $(\Delta^2\pi/K)^{\frac{1}{2}}$ in the cold-film response function $A(f) = \exp[-(\Delta^2\pi f/K)^{\frac{1}{2}}]$. For details, see Section 2.2.2.



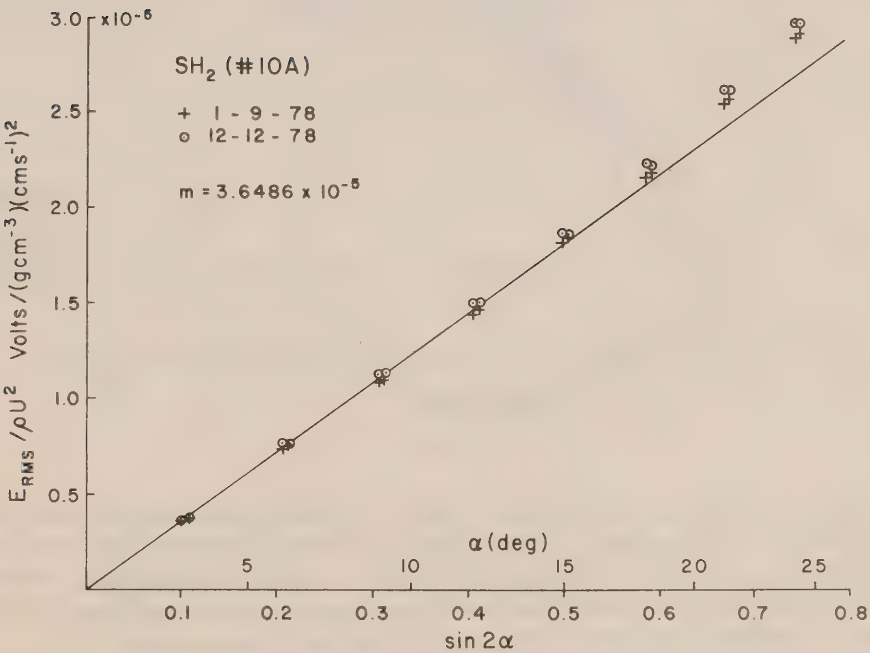
$$\sin 2\alpha = 2\sin\alpha\cos\alpha \doteq 2\frac{v}{U}$$

for small α,
ie. $v \ll U$

Figure 13: Geometry of airfoil probe operation. The total velocity vector $\underline{U}_T$ has components U and v, respectively parallel and perpendicular to the airfoil probe axis. The probe senses a side force proportional to v.



(a)



(b)

Figure 14: Calibrations of airfoil probes before (+) and after (⊙) the field operation in Knight Inlet. For angles of attack less than 12°, the calibrations are linear with slope m_i: probe sensitivity $S_i \equiv 2\sqrt{2}\, m_i$.

(a) i = 1, probe orientation gives output $\propto$ w.

(b) i = 2, probe orientation gives output $\propto$ v.

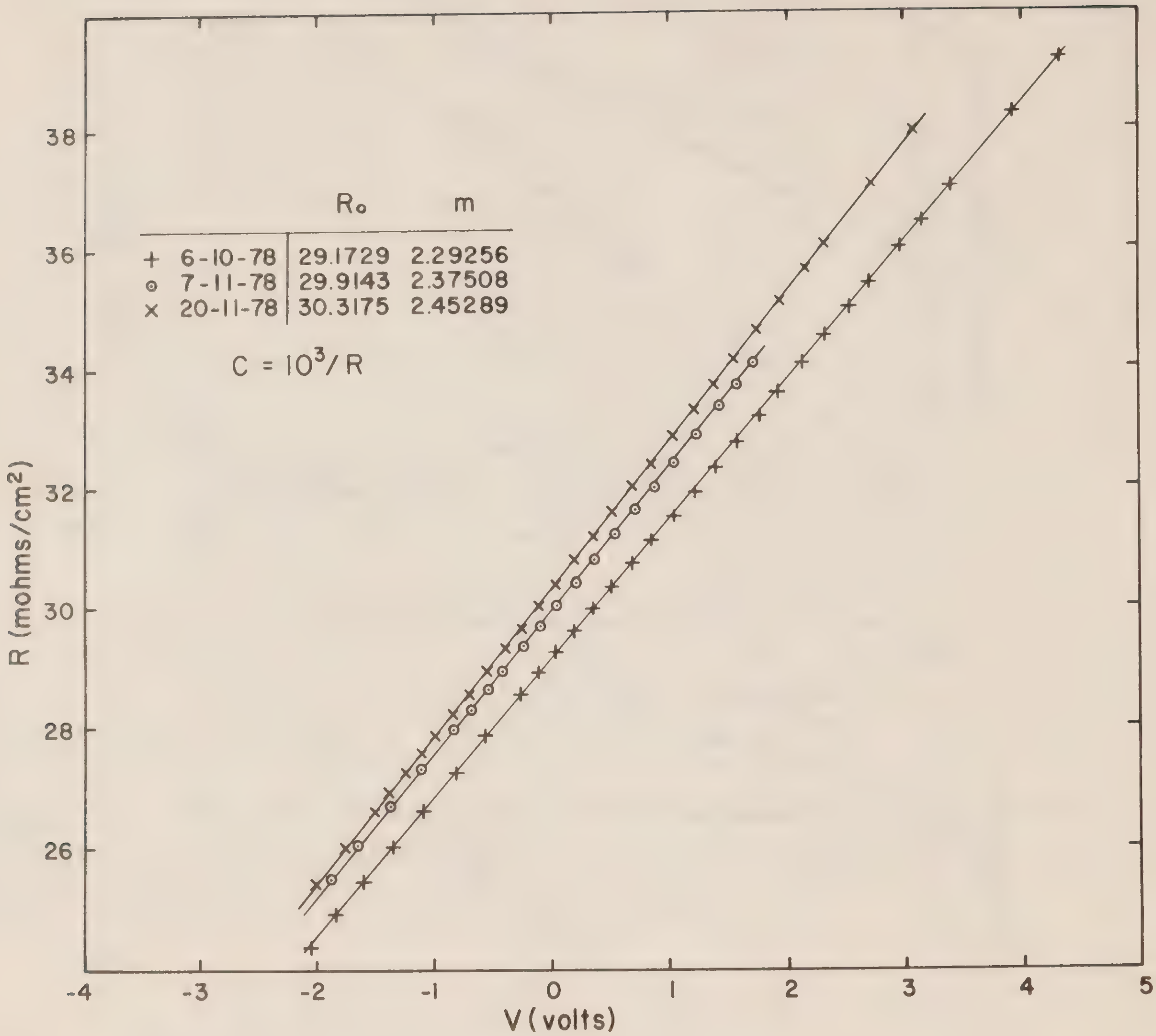


Figure 15: Laboratory (+) and field (⊙, x) calibrations of the conductivity sensor. Resistivity R(mohm/cm^2) is a highly linear function of sensor output voltage V, but the calibration was not stable. Since an ambient temperature sensitivity is suspected, we use the calibration (x) carried out in Knight Inlet, where air temperature was closest to water temperature.

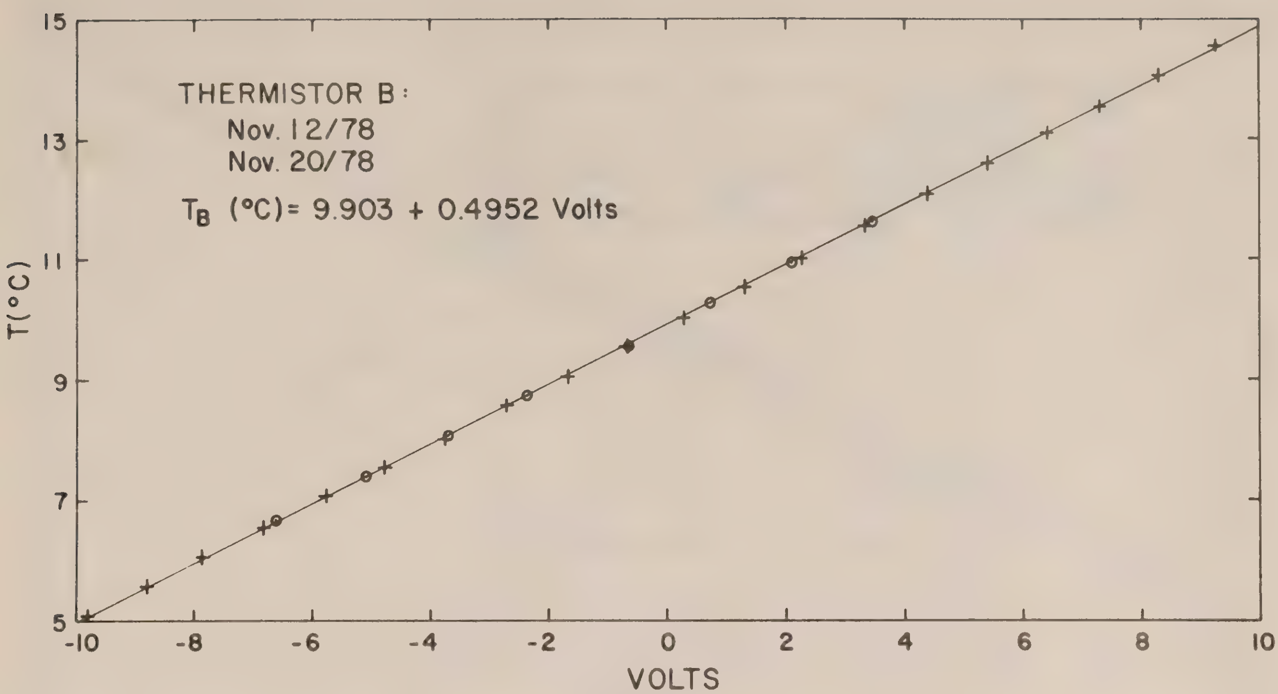


Figure 16: Calibration of upper thermistor TB before (⊙) and after (+) field work, against temperature measured by a quartz thermometer. The linear least squares fit is to the combined calibrations.

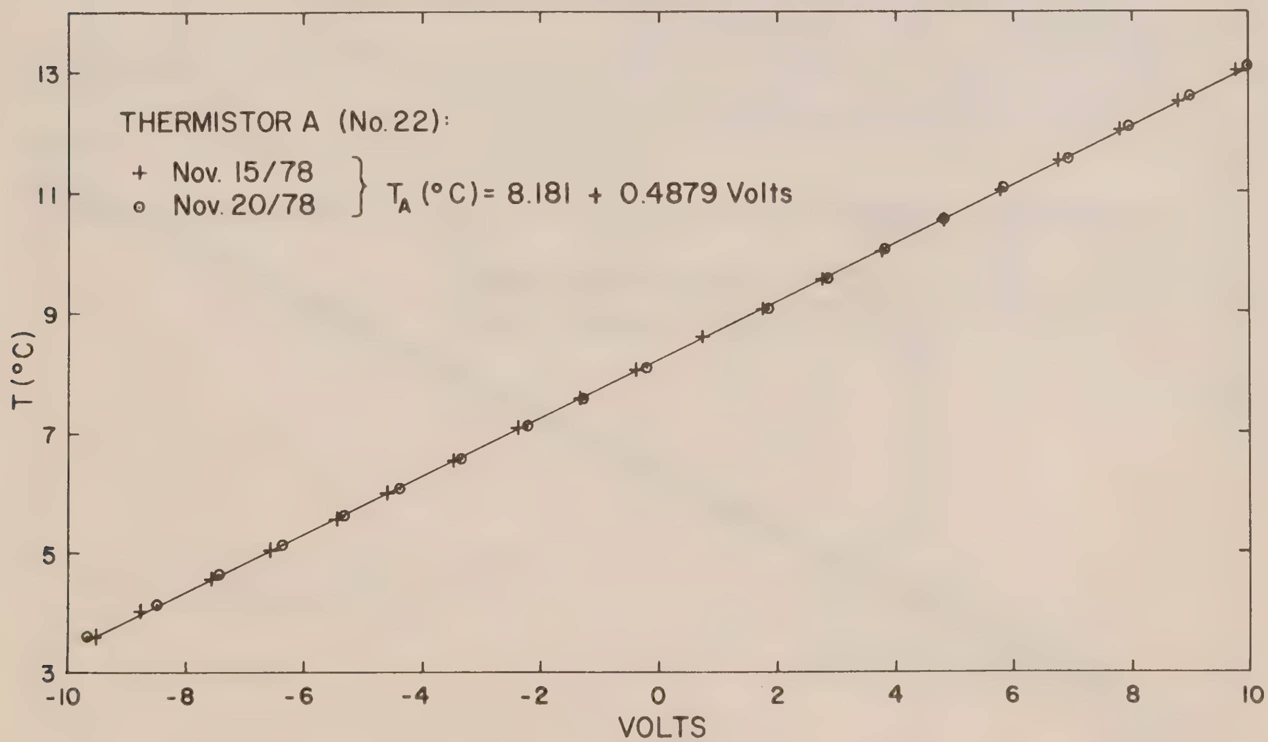


Figure 17: Calibrations of lower thermistor TA after installation (+) and at the end of field work in Knight Inlet (⊙). The linear least squares fit is to the combined calibrations.

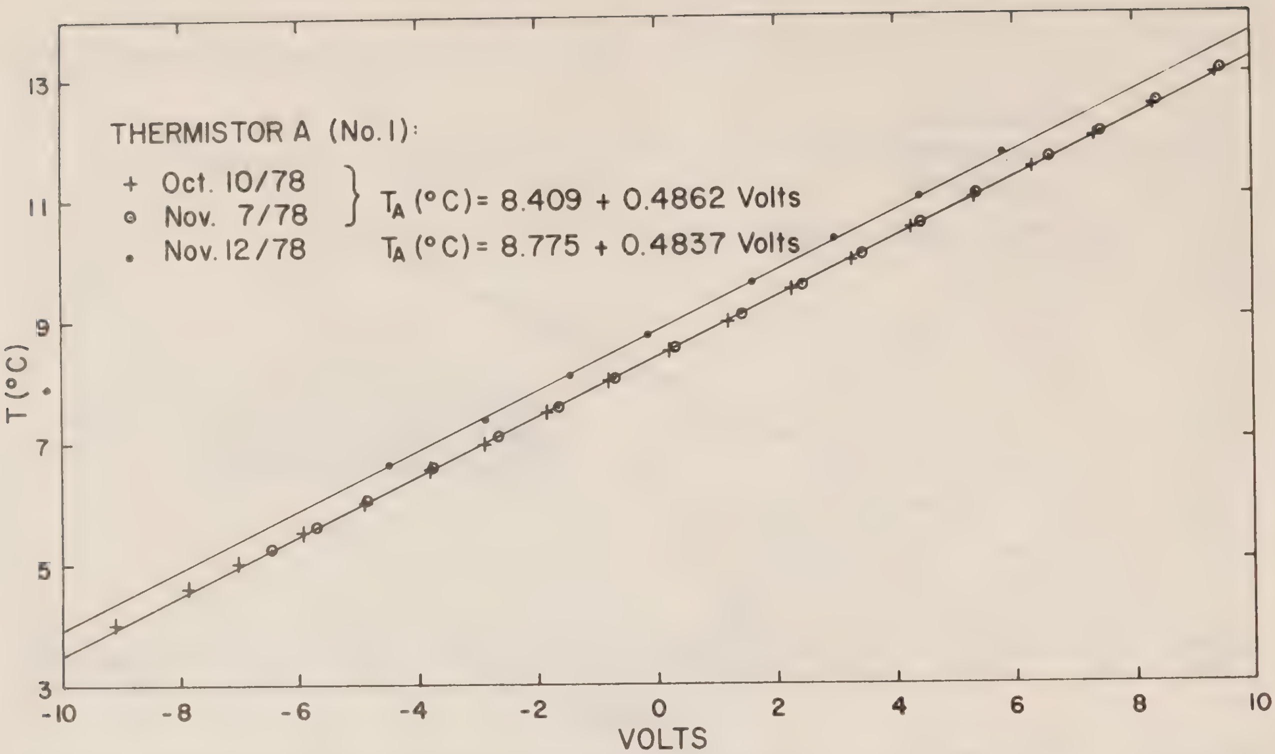
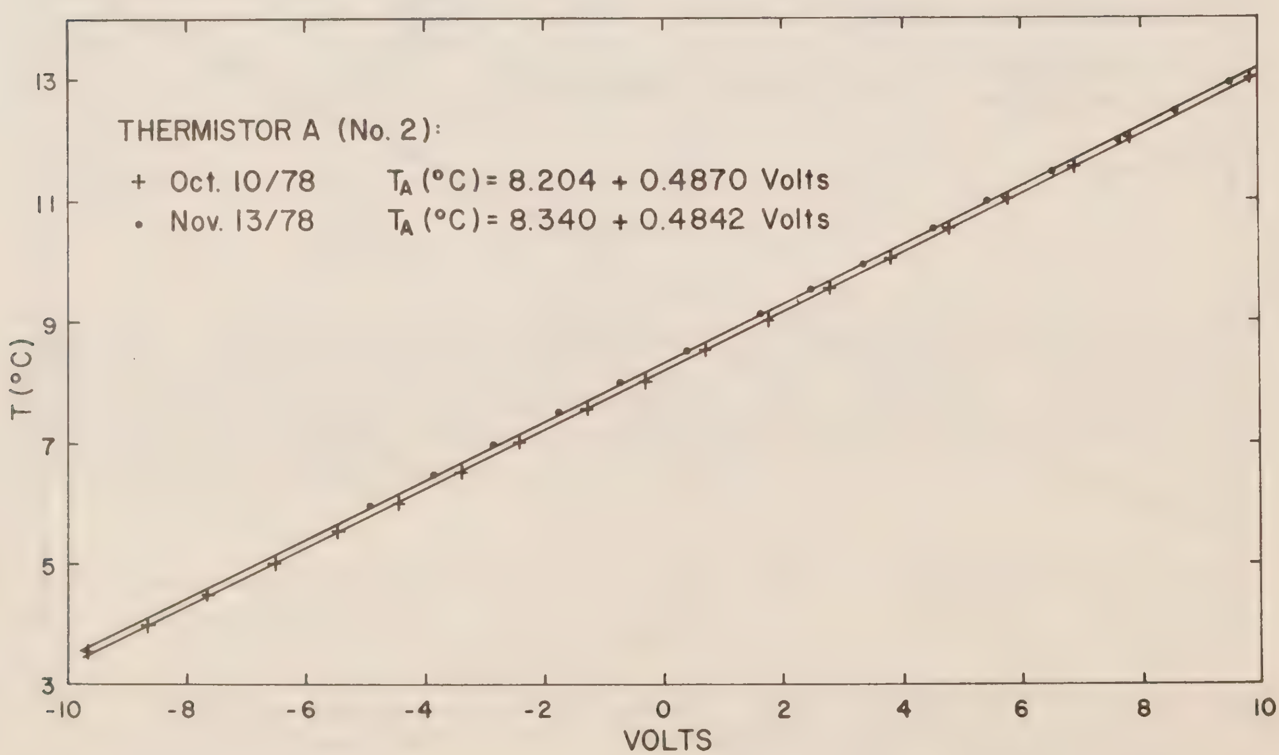


Figure 18: Calibrations of thermistors used during the early part of field work in Knight Inlet. The epoxy in which these thermistors were mounted absorbed water under pressure, resulting in frequent calibration shifts. The shift is predominantly an off-set, rather than a gain change.
(a) Thermistor #1 above (b) Thermistor #2. below



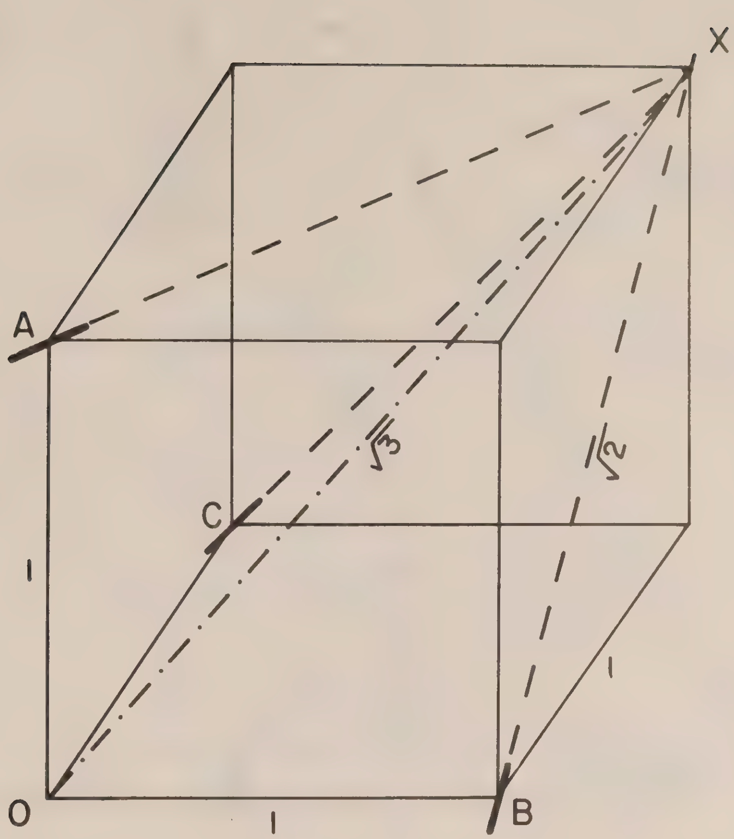
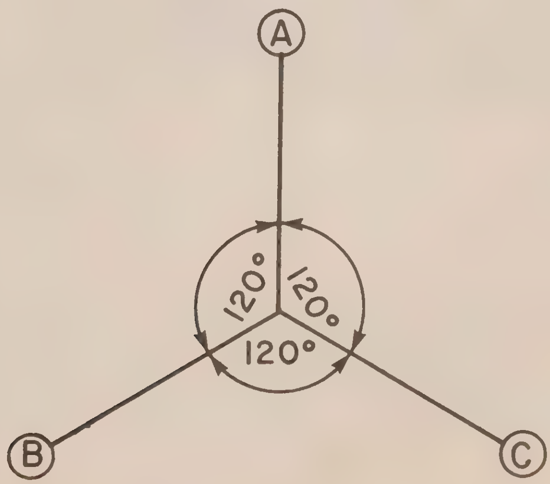
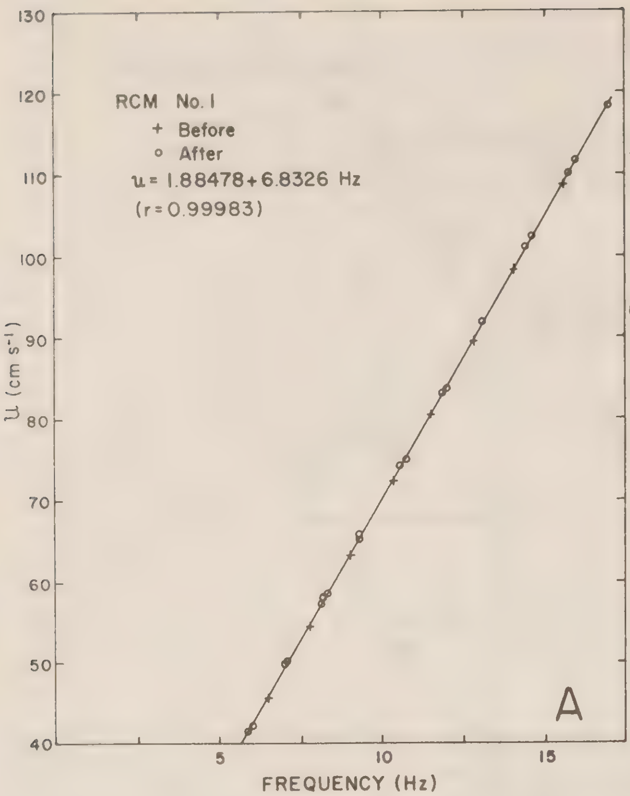


Figure 19(a): Geometry of rotor stems (OA, OB, OC) and rotor axles (heavy short lines parallel to AX, BX, CX) relative to the axis OX of the turbulence sensors. Each rotor axle makes an angle $\gamma = \cos^{-1}\left(\sqrt{\frac{2}{3}}\right) = 35.26°$ with OX, so in the absence of cross-flows, all rotors sense $U\cos\gamma$.

Figure 19(b): Head-on view of rotor arrangement.





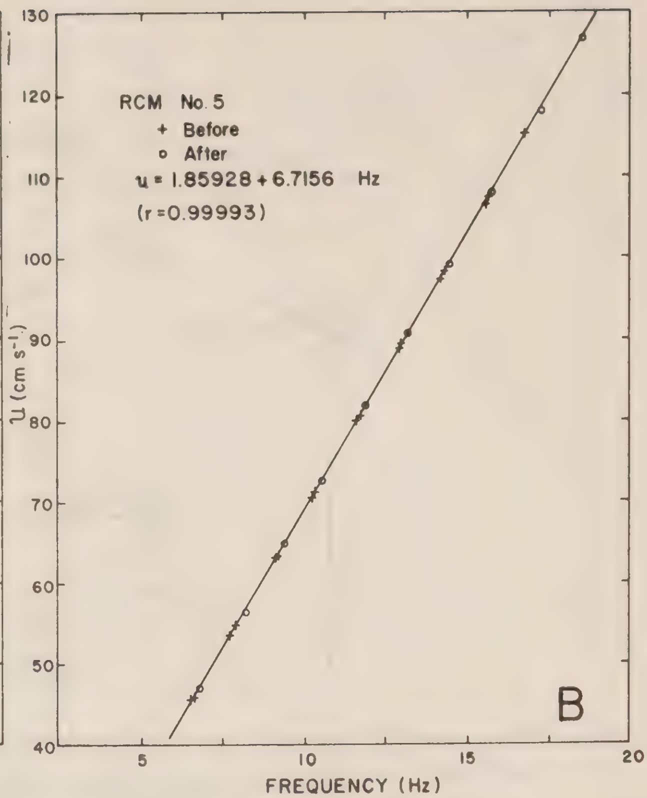
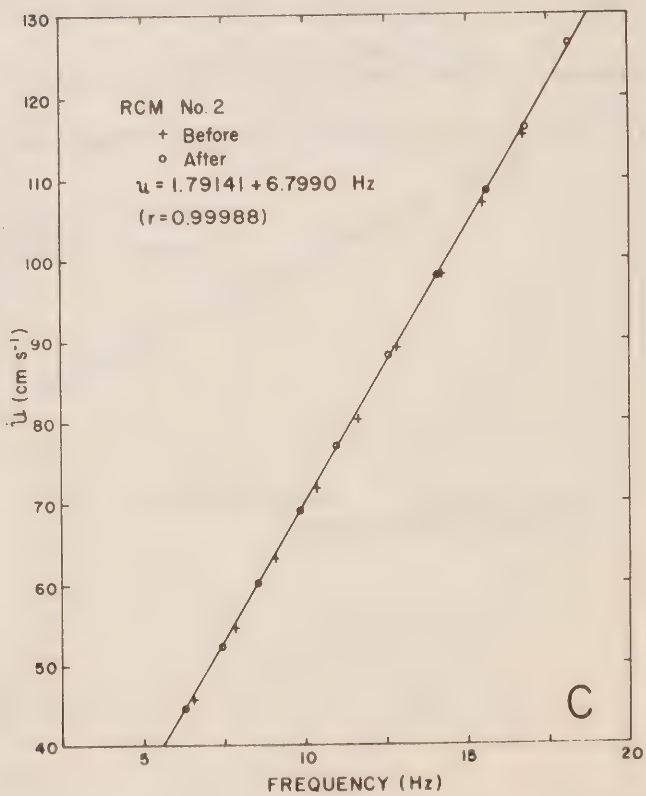


Figure 20: Before (+) and after (0) head-on calibrations for rotor heads used in Knight Inlet. U is the constant mean speed of water in the I.O.S. water tunnel. With a rotor axle aligned directly into this flow, the output frequency is measured. The linear least squares lines are fit to the combined set of calibration points for an individual rotor.



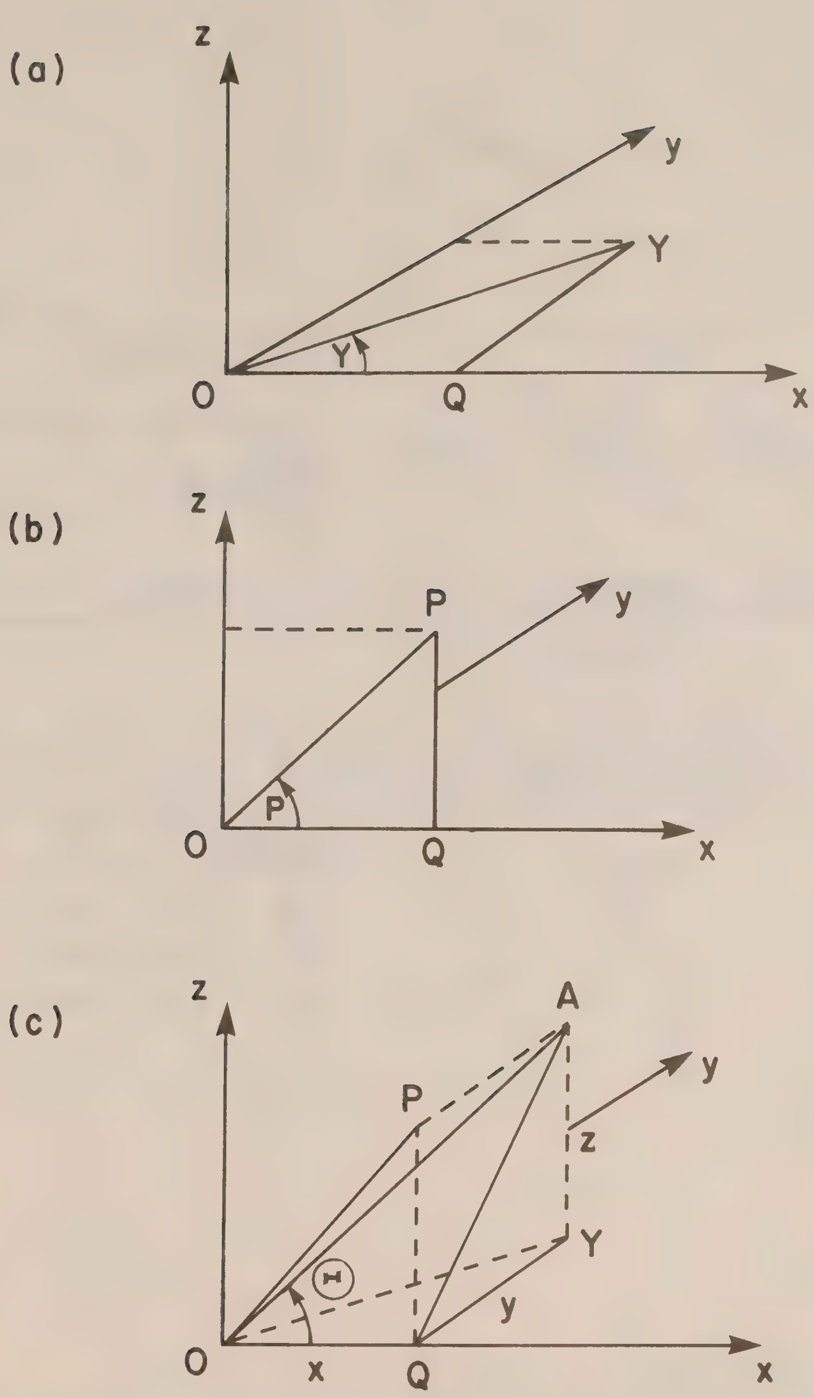


Figure 21: Definitions of (a) yaw angle Y of rotor axle OY and (b) pitch angle P of rotor axle OP relative to a calibration coordinate system with x-axis parallel to a steady mean flow. (c) illustrates the geometrical relationship among angles Y(= ∠ YOQ), P(= ∠ POQ) and Θ = total angle of attack between a rotor axle OA and a mean flow along OX.

$$(\tan \Theta)^2 = \left(\frac{AQ}{x}\right)^2 = \left(\frac{\sqrt{y^2 + z^2}}{x}\right)^2 = \frac{y^2}{x^2} + \frac{z^2}{x^2} = (\tan P)^2 + (\tan Y)^2$$

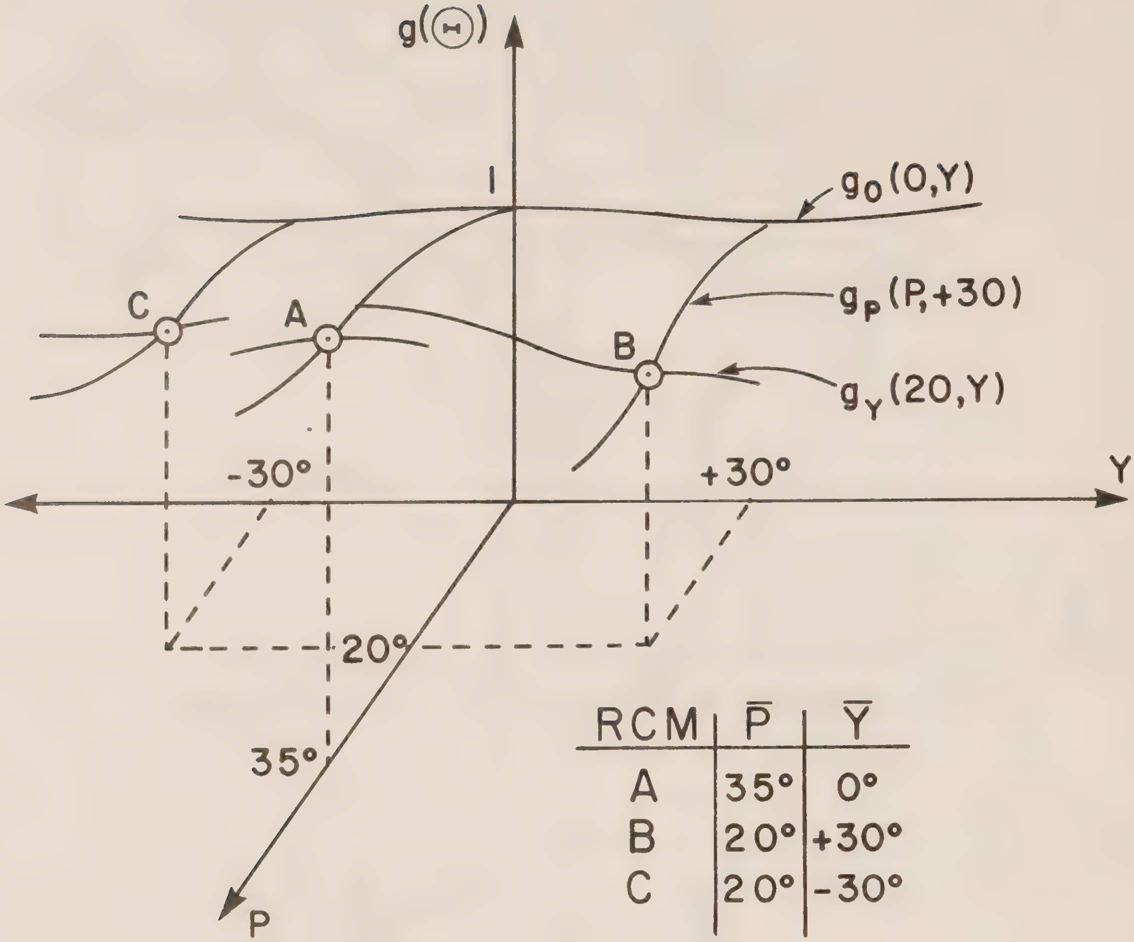


Figure 22: Position of A, B, and C rotors on the surface $g(\Theta) \equiv U\cos\Theta/(a + mf)$ where $U\cos\Theta$ is the true axial component of flow through the rotor and $(a + mf)$ is the measured axial component. If the rotors were a true speed sensor, i.e. had a cosine response, $g(\Theta)$ would be 1.0: our rotors tend to overspeed slightly at non-zero angles of attack, so that $g(\Theta) < 1.0$. Mean pitch ($\bar{P}$) and yaw ($\bar{Y}$) angles for each rotor are determined by the triplet configuration (Figure 19(a) and (b)) in the situation of zero cross-flows ($V = W = 0$).

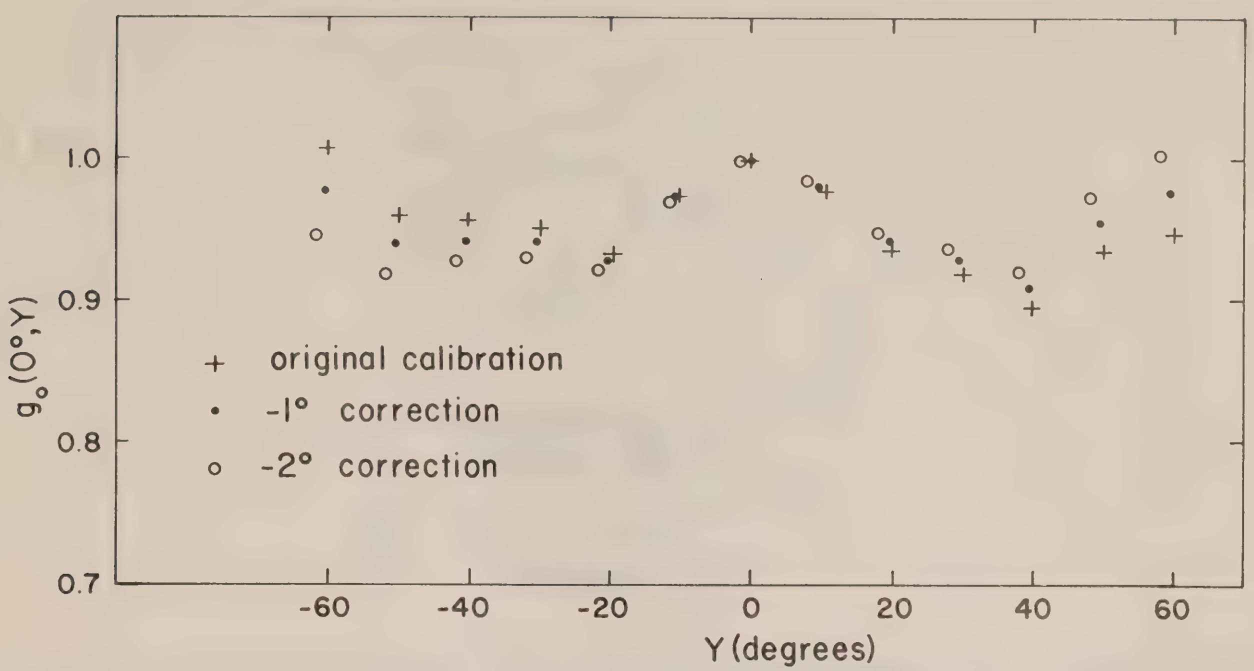


Figure 23: Rotor response as a function of yaw angle Y at zero pitch. Forcing $g_o(0°,Y)$ to symmetry about Y = 0° determines a zero correction which reduces error in measured yaw to ±0.5°. For the rotor shown in this example, Δ = -1°.

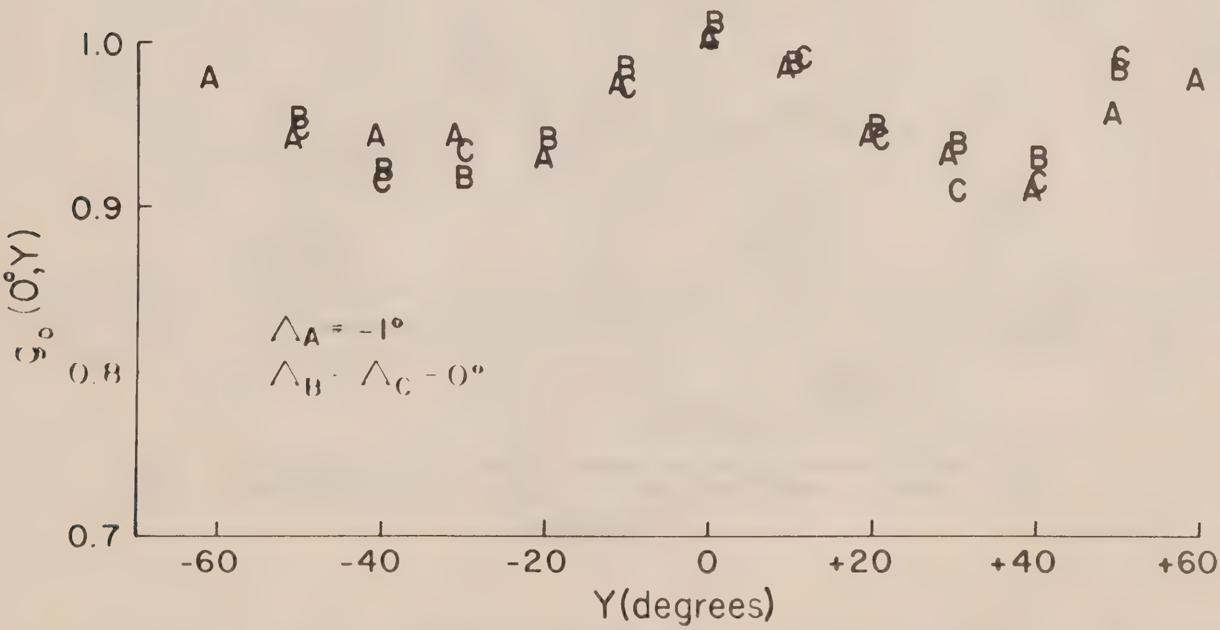


Figure 24(a): The calibration section $g_o(0°,Y)$ for the three rotors used in Knight Inlet. The yaw correction noted for each rotor has been applied before plotting these curves and is used to correct Y in the two following calibration sections.

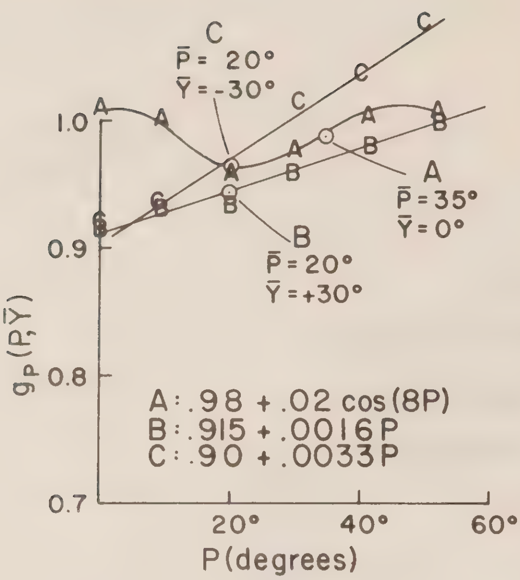


Figure 24(b): The calibration section $g_P(P,\bar{Y})$, rotor response as a function of pitch P at the mean yaw angle $\bar{Y}$ appropriate to the individual rotor. The The responses are fitted by the solid curves shown and noted in parametric form below as a function of P in degrees.

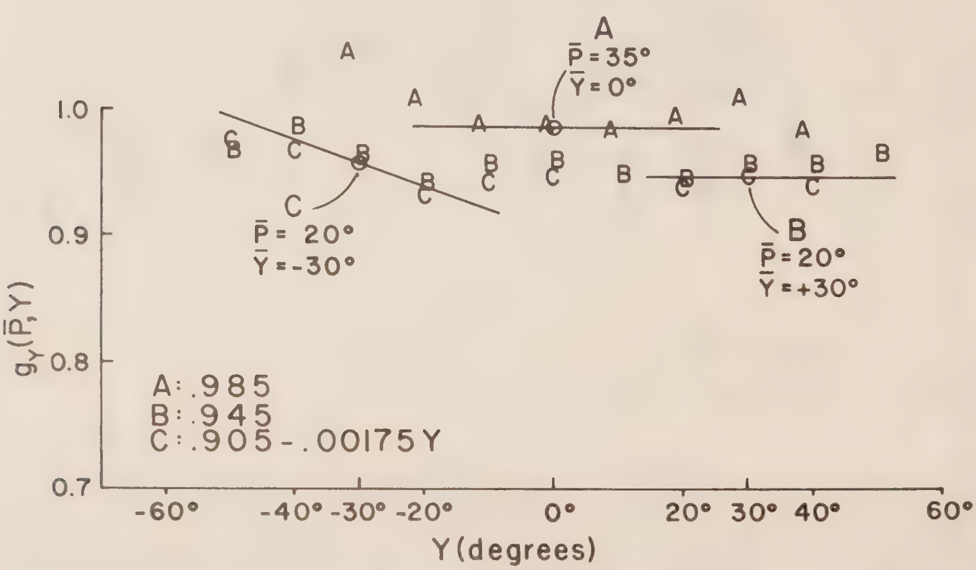


Figure 24(c): The calibration section $g_Y(\bar{P},Y)$, rotor response as a function of yaw Y at the mean pitch angle $\bar{P}$ appropriate to the individual rotors. The responses are fitted by the solid lines shown and noted below in parametric form as functions of Y in degrees.

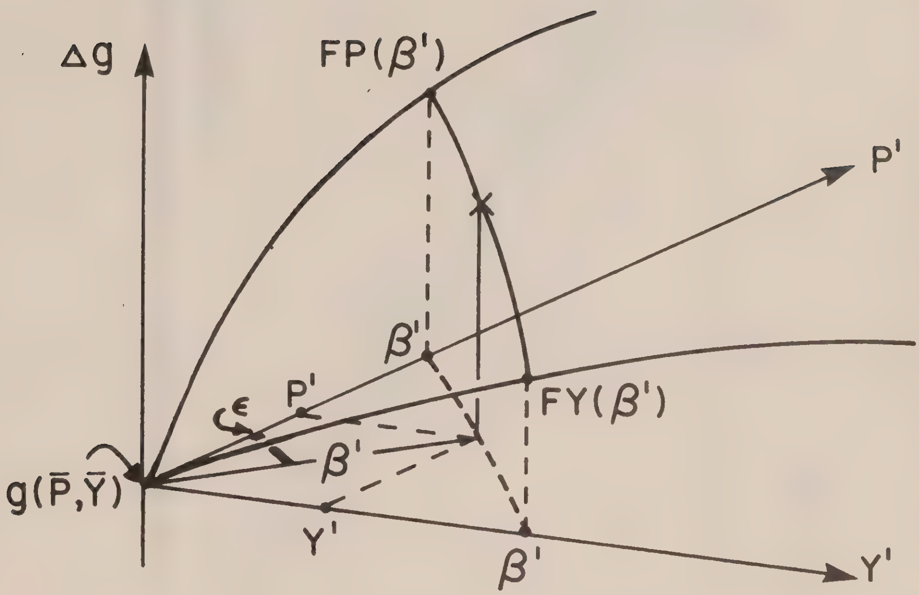


Figure 25: Geometry of interpolation on the rotor response surface $g(P,Y) = g(\bar{P},\bar{Y}) + \Delta g$ for small variations P' and Y' of pitch and yaw from the mean values characteristic of the rotor.

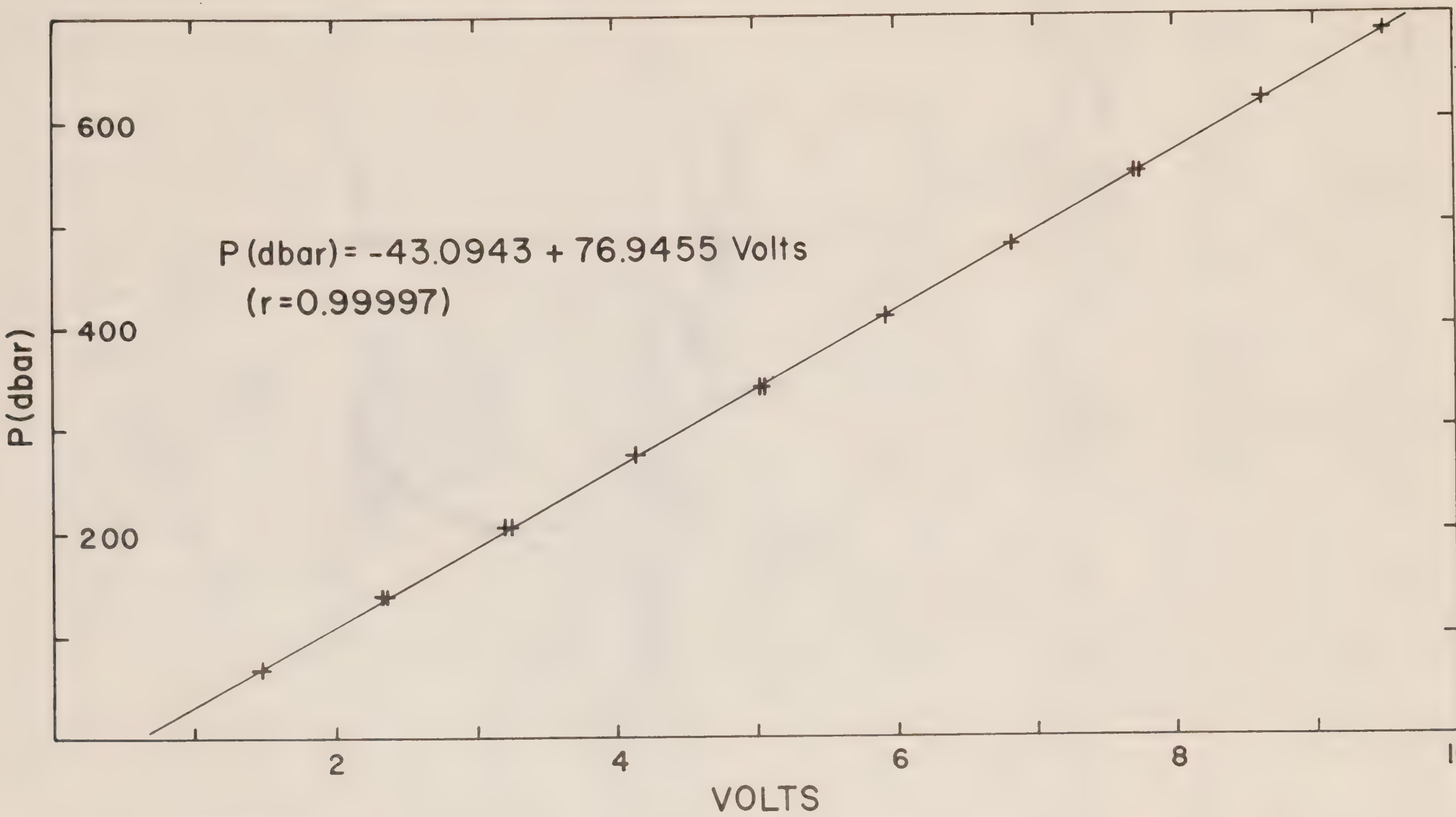


Figure 26: Calibration of the pressure sensor carried on PISCES, against pressure measured by a dead-weight tester.

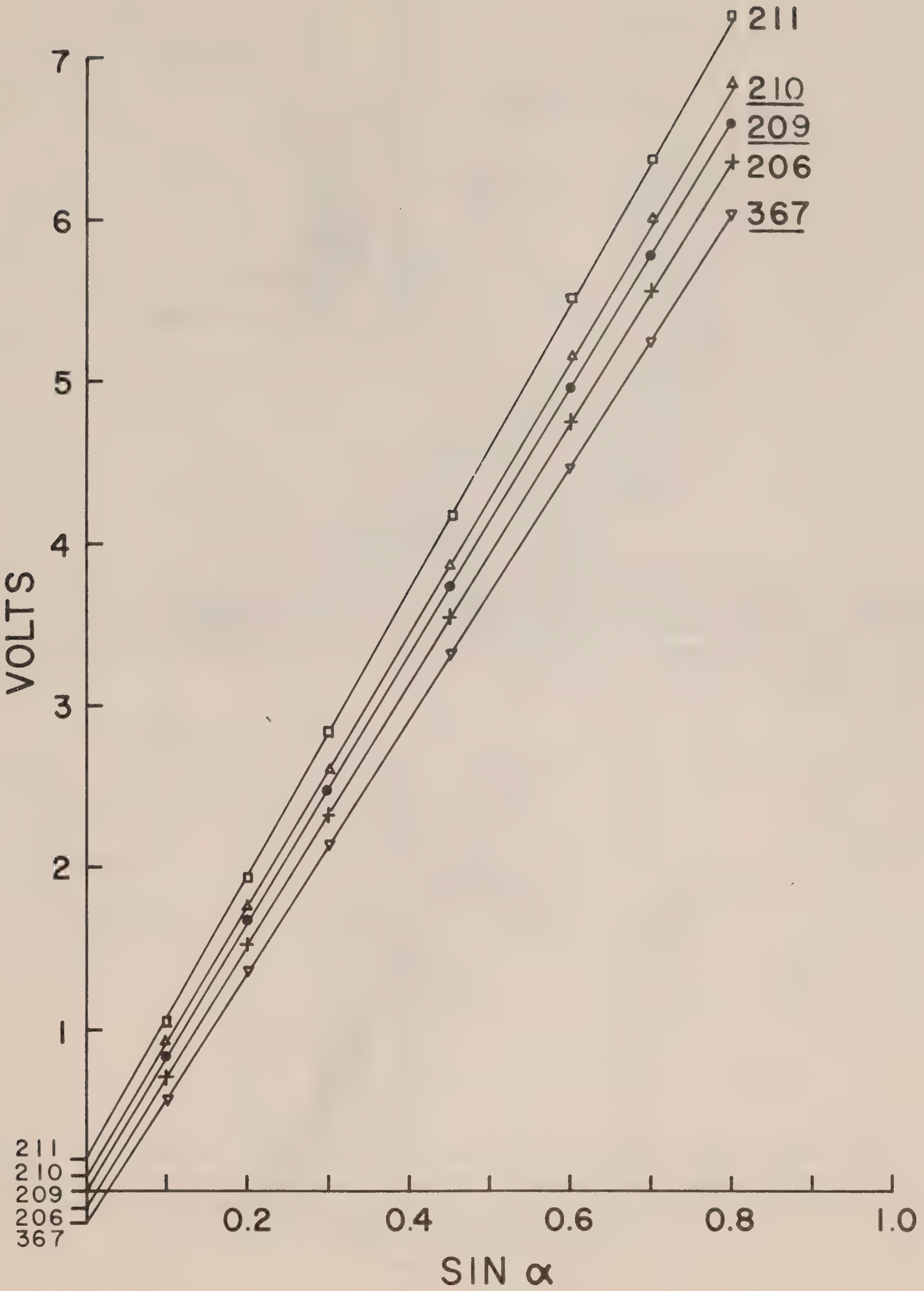


Figure 27: Calibrations of the output of the three (underlined) high-frequency response accelerometers carried on PISCES, as a function of sinα where α is the angle from horizontal (for clarity, the curves are off-set from one another by the amounts shown at left).

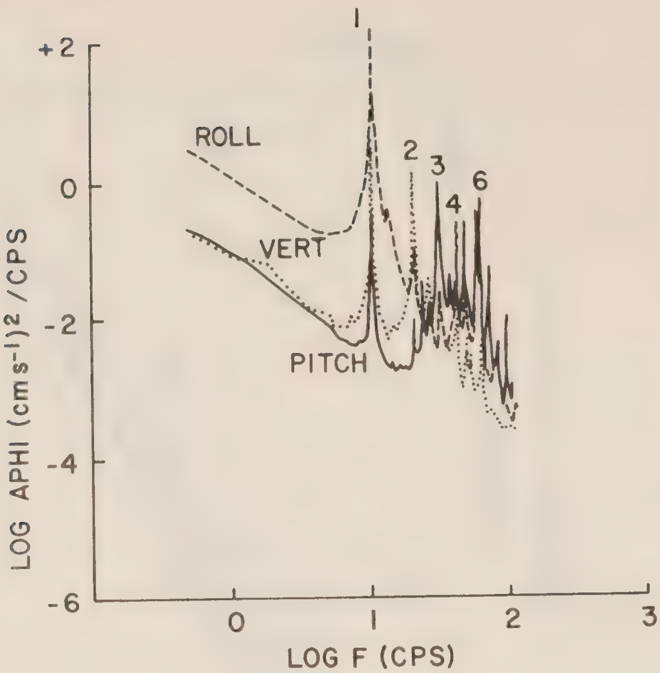


Figure 28: Acceleration spectra from three orthogonal accelerometers carried immediately behind the turbulence sensors. The peak marked 1 at 10.8 Hz is the fundamental vibration frequency of the submersible propulsion system: higher harmonics are noted.

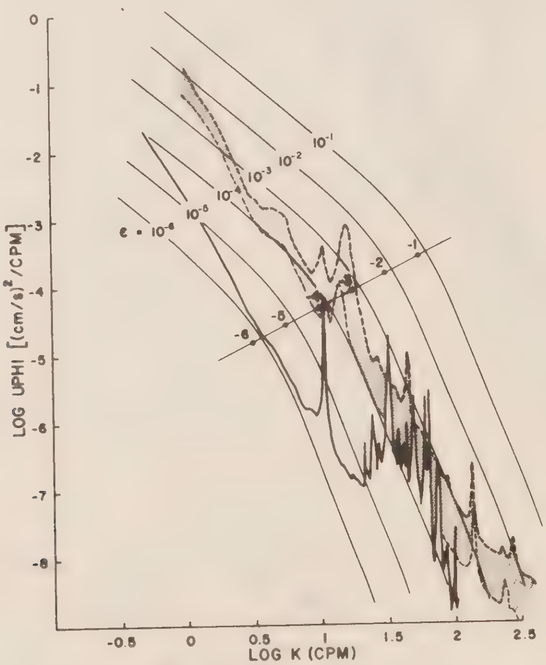


Figure 29: Axial "velocity" spectrum (formed by dividing measured axial acceleration spectral values by $(2\pi f)^2$) superimposed on a hierarchy of universal spectra ordered by the value of $\varepsilon(cm^2\ s^{-3})$, the rate of dissipation of turbulent kinetic energy. The shaded region is a range of noise-level axial velocity spectra obtained from a hot-film sensor mounted on a depth-controlled towed system.

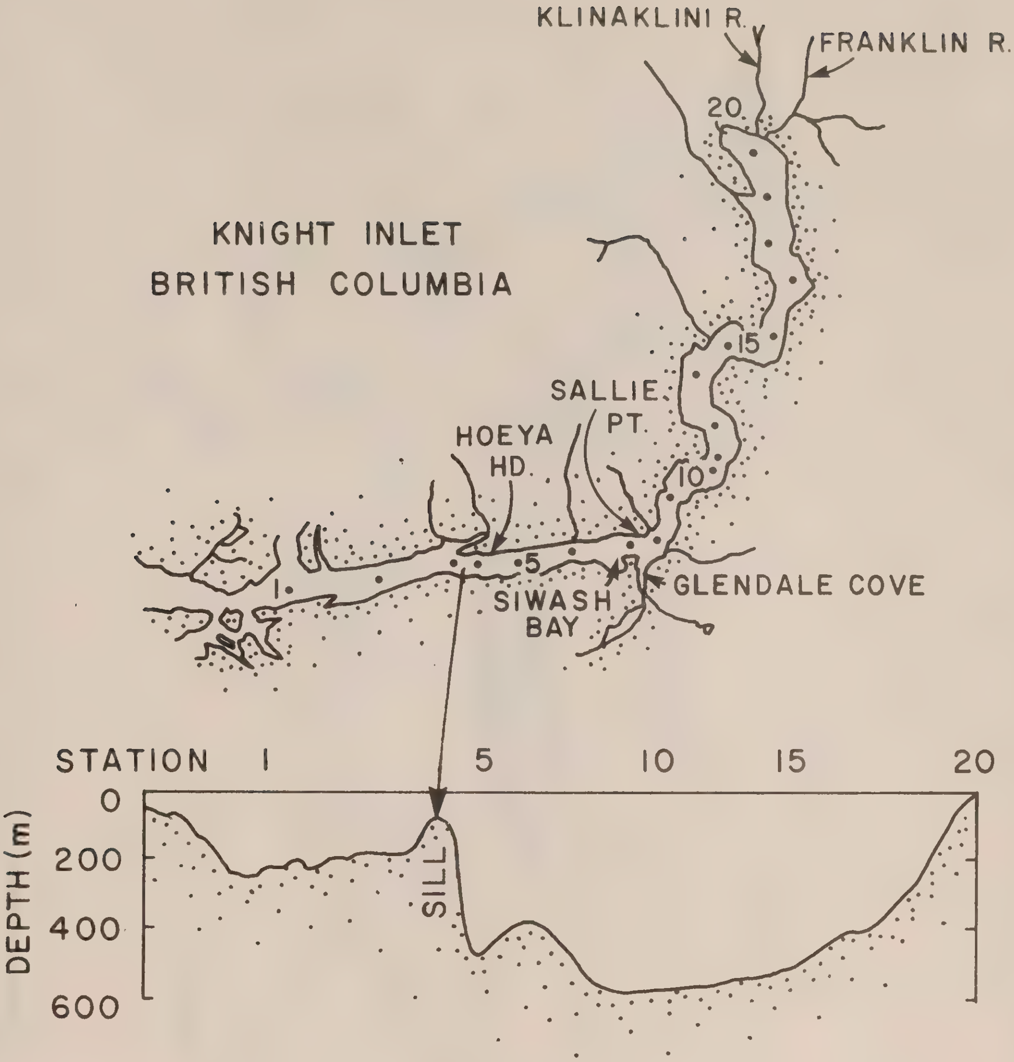
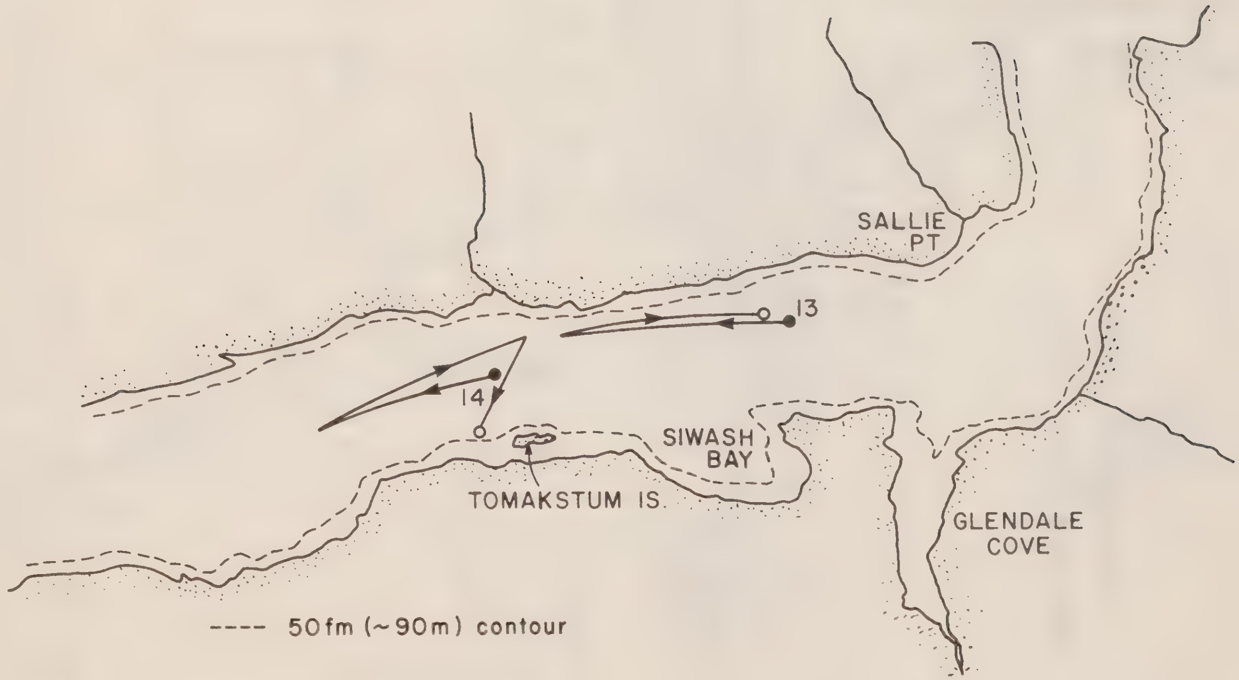


Figure 30: Knight Inlet, British Columbia is a narrow steep-sided inlet consisting of a shallow (∿ 200 m) outer basin separated from a deeper (∿ 600 m) inner basin by a submarine sill rising within 63 m of the surface at Hoeya Head. (Figure after Farmer and Smith (1978)).



<u>Figure 31</u>: Location and approximate tracks of PISCES dives in Knight Inlet: a solid (open) circle marks the launch (recovery) position of each dive. Dives through the internal wave train:

<u>Figure 31(a)</u>: November 13 and 14, 1978.

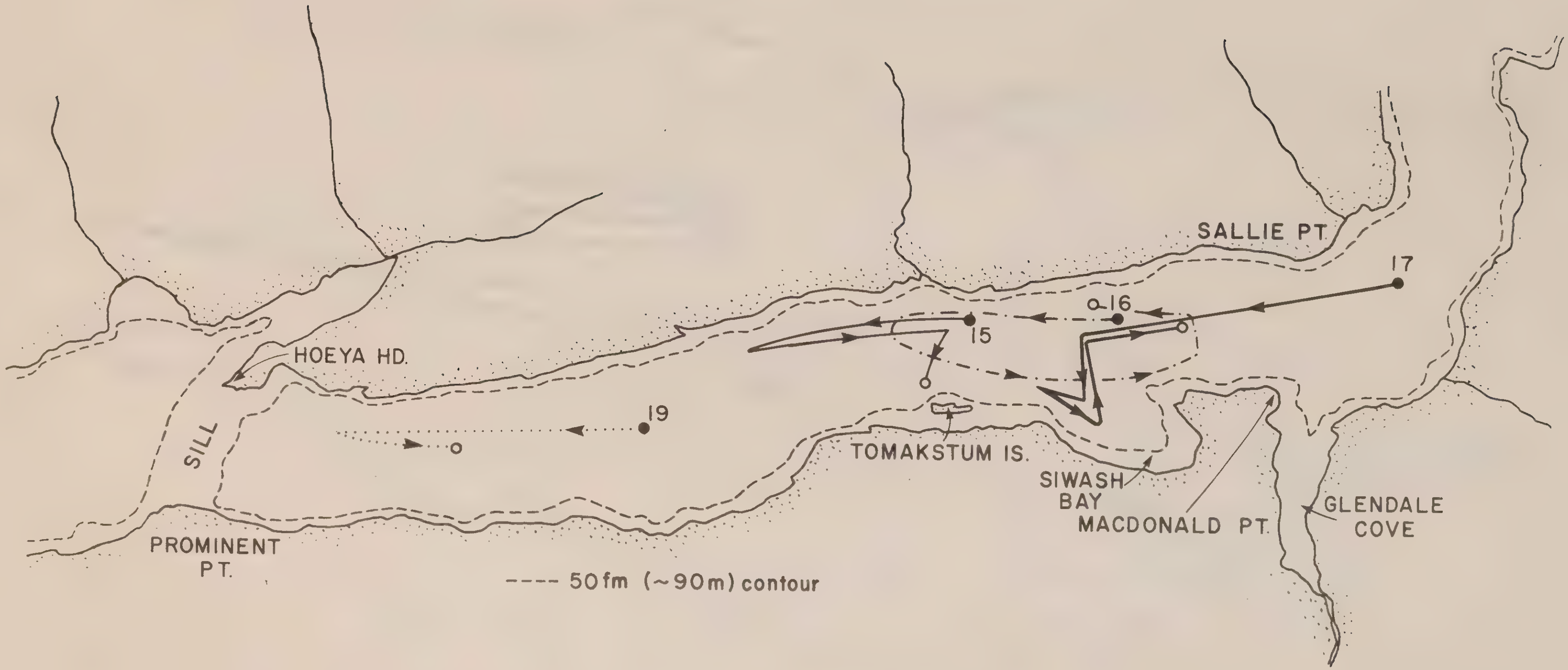
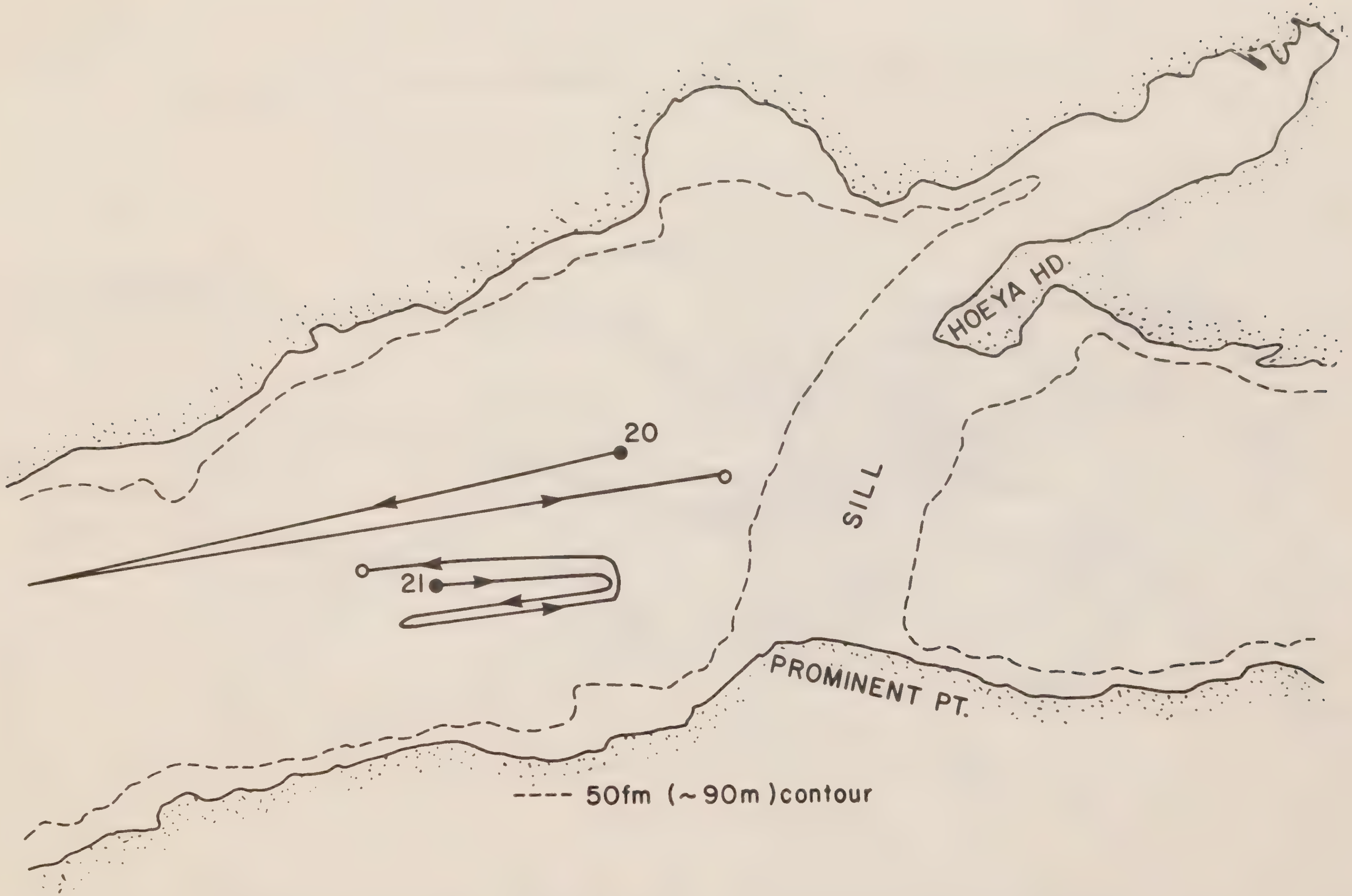


Figure 31(b): November 15 through 19, 1978 (no dive Nov. 18).



Dives in a near-surface mixing regime:

Figure 31(c): November 20 and 21, 1978.

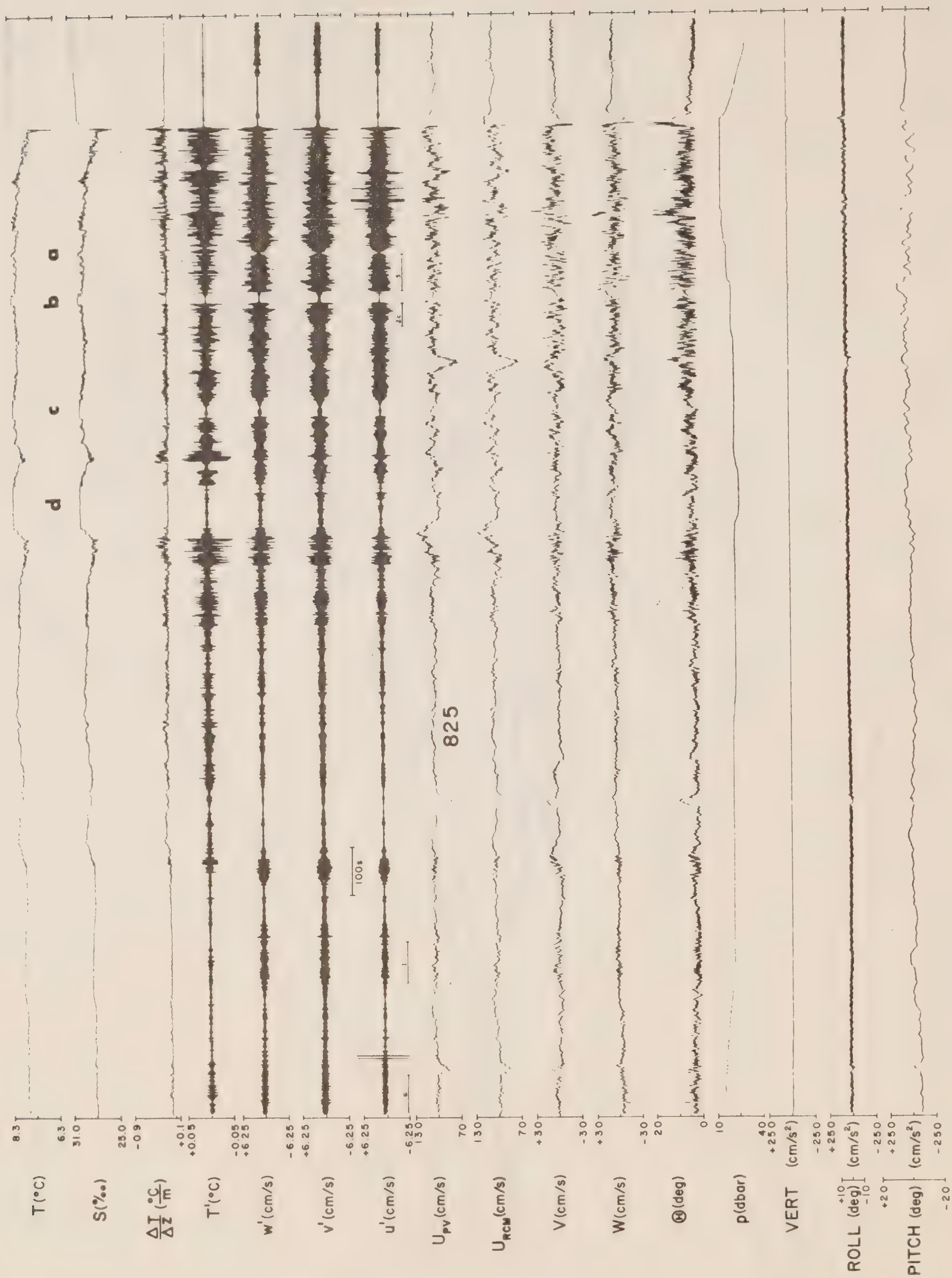

T(°C)
S(‰)
ΔT/ΔZ (°C/m)
T'(°C)
w'(cm/s)
v'(cm/s)
u'(cm/s)
U_PV(cm/s)
U_RCM(cm/s)
V(cm/s)
W(cm/s)
Θ(deg)
p(dbar)
VERT (cm/s²)
ROLL (deg) (cm/s²)
PITCH (deg) (cm/s²)
825
100s
a
b
c
d

Figure 32: Calibrated analog signals from turbulence and auxiliary sensors carried on PISCES, as the submersible travels from the rear (left) through the front (right) of an internal wave train in Knight Inlet. For detailed discussion, see Section 3.

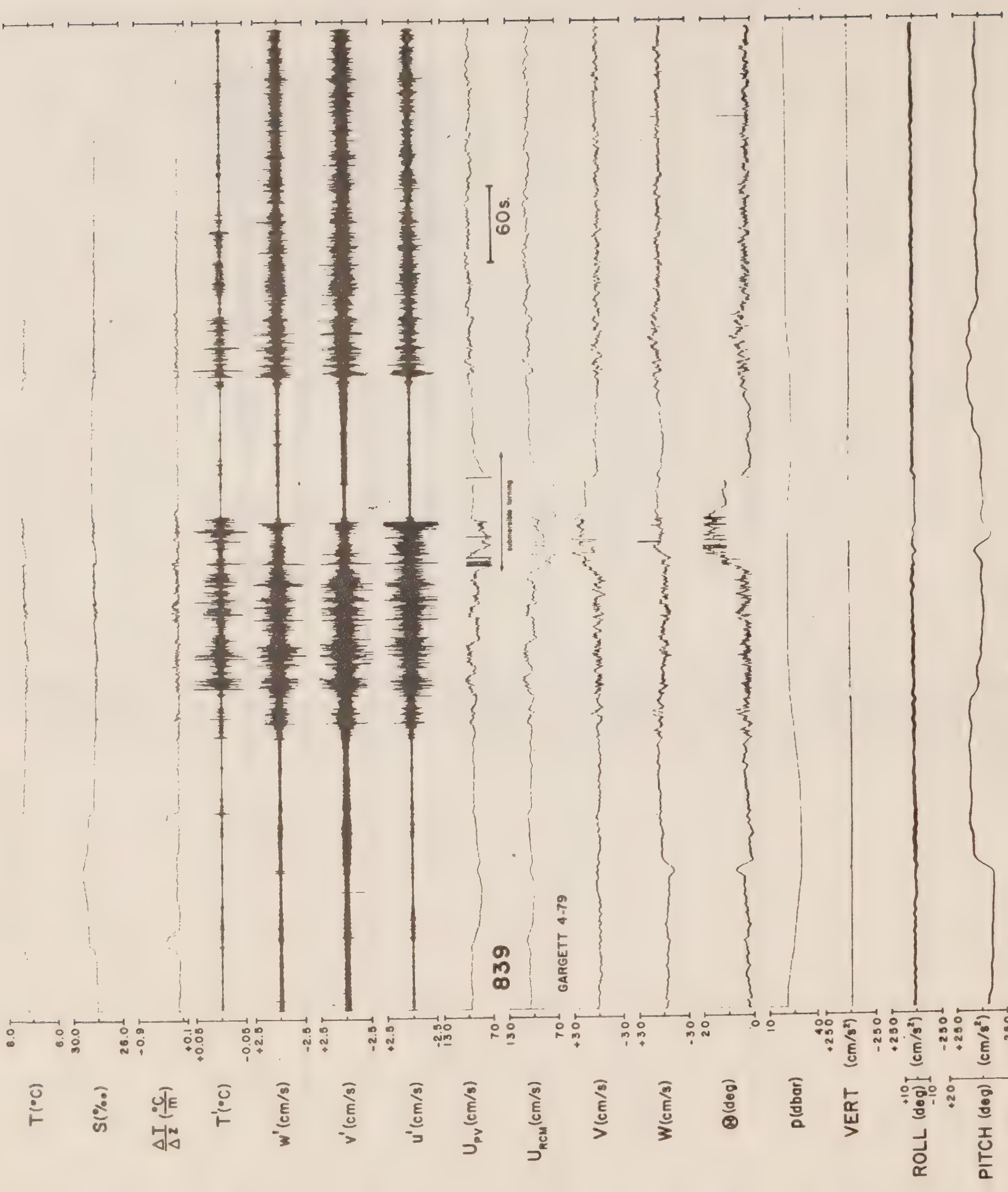

T(°C)
S(‰)
ΔT/Δz (°C/m)
T'(°C)
w'(cm/s)
v'(cm/s)
u'(cm/s)
U_PV(cm/s)
U_RCM(cm/s)
V(cm/s)
W(cm/s)
Θ(deg)
p(dbar)
VERT (cm/s²)
ROLL (deg) (cm/s²)
PITCH (deg) (cm/s²)
60s.
submersible turning
839
GARGETT 4-79

Figure 33: Calibrated analog signals from turbulence and auxiliary sensors carried on PISCES, as the submersible travels through a near-surface mixing regime close to the submarine sill across Knight Inlet.

Pacific Marine Science Report 80-7

AN INVENTORY OF PHYSICAL OCEANOGRAPHIC INFORMATION FOR THE WATERS OF QUEEN CHARLOTTE SOUND, HECATE STRAIT, DIXON ENTRANCE AND THEIR VICINITY

by

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1980

Abstract

A survey of published and unpublished oceanographic data taken in Queen Charlotte Sound, Hecate Strait, Dixon Entrance and their contiguous waters has been made and the source and availability of these data indicated. The data include daily observations of sea-surface temperatures and salinities from coastal stations; hydrographic, STD, CTP and BT casts, tidal height, current velocity and wave measurements and temperature data from thermistor chains.

Introduction

The waters of the Queen Charlotte Sound, Hecate Strait, Dixon Entrance and of their vicinity (hereinafter referred to as the region) have traditionally been important as commercial waterways, commercial and recreational fishing, and fisheries research and exploration. In recent years, however, the need for marine environmental information for the region has risen appreciably due particularly to interest in underwater petroleum exploration, threat of pollution from potential tanker traffic, search for little-utilized marine renewable resources such as sea weeds and certain fish species, and search for sites that have potentials for electric power generation from ocean waves and wind energy. As a consequence, there has been an increasing requirement for oceanographic information for the region, particularly physical oceanographic data. In order to facilitate the efficient use of the available data that were collected by a number of agencies during the past an effort is made to compile an inventory of all available information, either stored at the respective agencies or archived at the responsible national data centres such as the Marine Environmental Data Services Branch (MEDS) of the Department of Fisheries and Oceans (Ottawa).

Data Sources

Much of the data archived at MEDS is available in standardized magnetic tape data format while those stored at the data collecting agencies, principally Pacific Biological Station (Nanaimo), Institute of Ocean Sciences (Sidney), Department of Oceanography of the University of British Columbia (Vancouver) and Defence Research Establishment Pacific (Esquimalt), are not. Their data are stored in one of the following formats: original field sheets, tabulations of summarized data, IBM cards, computer print-outs, and unstandardized magnetic tapes. The data obtained recently, during the past year or so are, of course, in the preliminary stages of processing and are not readily available.

Types of Data

Hourly tidal heights

The records of hourly tidal heights compiled for the coast stations constitute the longest time-series oceanographic data available for the region. They have been observed by the Canadian Hydrographic Service at 15 sites (Table 1) at one time but at present observations are made from only five stations (Prince Rupert, Bella Bella, Port Hardy, Queen Charlotte City and Langara Point) (Fig. 1). The earliest observations were made at Prince Rupert in 1906. Among other things these data form the basis for providing tidal predictions for the region (e.g. tide tables). Most of the original records are kept on file at the Institute of Ocean Sciences (IOS) while the archived data are stored on magnetic tapes at MEDS. The hourly values are not published but the maximum and minimum daily heights as well as daily and monthly mean heights are published annually by the Canadian Hydrographic Service and are generally available for any year within two years after the termination of observations in any calendar year (e.g. Canadian Hydrographic Service, 1979a; 1979b). A copy of the archived data from 1975 to present is available at the IOS.

Tidal height data have also been collected at eight sites in the general vicinity of Douglas Channel and Gardner Canal, with bottom-mounted pressure recorder, during 1977-1978 by Dobrocky SEATECH Ltd. (Webster and Ford, 1979; Webster, 1979a). The data are archived on magnetic tape at IOS.

Daily seawater observations

Sea-surface temperatures and salinities and sometimes densities have been observed daily at a number of coastal stations, usually lighthouses, for as much as half a decade at some locations in the region. There had been a total of 14 such stations (Table 2) operating at one time or another in the region but at present there are only less than one half of the above still operating, (Langara Island, Bonilla Island, McInnes Island, Cape St. James, Egg Island and Pine Island) (Fig. 1). The data were collected by the Pacific Biological Station and the Pacific Oceanographic Group of the Fisheries Research Board of Canada until 1970 but by the IOS since. The original data are kept on file at the IOS but the archived data on magnetic tape are available from MEDS. The daily observations are published annually, generally within two years of the termination of observations in the calendar year. The earlier data reports were published by the Fisheries Research Board of Canada (e.g. Hollister, 1974), Canadian Oceanographic Data Centre, the predecessor of MEDS (e.g. Canadian Oceanographic Data Centre, 1968) and since 1970 by the IOS (formerly called Marine Science Directorate Pacific Region) (e.g. Giovando, 1980).

Oceanographic observations from hydrographic stations

Much of the oceanographic observations in the region consist of hydrographic-station data (sometimes called hydrographic cast or bottle-cast data). They consist of measurements of temperatures (with reversing thermometers) and sampling of water at various depths, usually at international standard depths, at each geographical location called a "station." The water samples obtained at each depth are determined for salinity and usually for dissolved oxygen content. In some cruises other chemical properties of water such as silicates, phosphates, nitrates, etc. are also determined. A hydrographic station also contains pertinent meteorological data such as air temperature and wind velocity. Since 1948 it also consists of bathythermograph data (continuous temperature with depth) to depths of 135m or 275m or to near the ocean bottom whenever the station depths were less than the limiting depth of the instrument. With the introduction of salinity-temperature-depth recorder (STD) and conductivity-temperature-pressure recorders (CTP) in late 1969 bathythermograph observations are not made at each station routinely. STD or CTP observations have recently replaced hydrographic casts but the latter are still made in order to monitor the performance of STD or CTP and to obtain water samples for dissolved oxygen content and other chemical properties.

Hydrographic-casts data have been collected in the region ever since 1934 and they have been taken at irregular intervals mainly by the Pacific Oceanographic Group of the Fisheries Research Board of Canada until 1970. Since 1967 the bulk of the data were taken with STD or CTP. Table 3 shows the summary of such data taken in the region.

No attempt has been made to include a table containing a list of

station positions or figures indicating these positions as this would make the report unnecessarily long.

The great majority of data have been published (e.g. Joint Committee on Oceanography, 1956; Scripps Institution of Oceanography of the University of California, 1965; Dodimead et al, 1961, etc.) and all of these data are archived and put on magnetic tape at MEDS. Data collected during 1967-1971 by the Fisheries Research Board of Canada (Dodimead, 1980a - 1980g) are archived at MEDS but the data records for these data have not been published yet. However, there are some data such as the 600-station observations made in Chatham Sound - Dixon Entrance during 1948 that are available only in their original field sheets. These unpublished data are kept on file at IOS.

Since May 1951 a large number of data have been taken by the Institute of Oceanography of the University of British Columbia in the inlets adjacent to the region and some within the region itself. The particulars related to these data are shown in Table 4. Most of these data are also archived at MEDS.

In conjunction with the fisheries research surveys conducted off the British Columbia coast by the staff of the Pacific Biological Station some oceanographic data are routinely collected. Such data consist of bathythermograph (BT) (both mechanical and expendable types) observations, surface temperature and salinity from bucket samples and occasionally salinity and temperature at depths from bottle casts. The data collected are summarized in the reports of the Pacific Biological Station (e.g. Westrheim, 1967; Butler and Smith, 1968; Harling et al, 1968; Levings, 1968; Davenport et al, 1971; Dodimead et al, 1980. None of these data are, however, archived at MEDS.

During 1977-1978 a few hundred CTP stations and some hydrographic stations have been taken in the waters in the general vicinity of Kitimat, B. C. (Douglas Channel, Gardner Canal, etc.) by Dobrocky SEATECH Ltd. (Table 4). Their data summary has been published (Webster and Ford, 1979; Webster, 1979a) and the data themselves are archived on magnetic tapes at IOS.

Current velocity measurements

Prior to 1967 most current velocity measurements were made with drift-pole or drift-drag (captive float) to observe surface currents and Ekman current meter to make subsurface measurements. The period of observations seldom exceeded two days. Since then most systematic current observations were made from moored buoys from which one or more recording current meters were suspended. It is not uncommon nowadays to make continuous observations at ½ or hourly intervals for as much as three months at a time. Ever since the first sustained series of measurements, lasting for 18 months, were made in the waters of British Columbia during 1968-1970 (Tabata and Stickland, 1971), and their data analysed (Chang, et al, 1976), it has become necessary to discontinue the short series of measurements of a few days and replace them with longer series lasting for several weeks. The relatively long series of data indicated that there were significant day-to-day changes of currents and against this background it became difficult to interpret those of short duration. In view of this, current velocity data taken over few

days are considered generally to be of limited use although they can be used as a very rough "guide" only where no other information is available. Great care must be exercised in the interpretation of such data as they may yield misleading information and any decision made on the basis of such interpretation may even give disastrous results (e.g. imagine locating a sewer outfall at a site where a short series of measurements indicated the desirability of the site which upon further measurements indicated otherwise).

Despite the shortcomings of these short series of measurements it is nevertheless useful, at this point, to list a summary of observations that have been made in the past as well as to indicate the long series of measurements that were made recently, if only to use the limited data as a basis for planning longer series of measurements at strategic locations. Table 5 lists practically all the current measurements that have been made in the region since 1948. It does not include the several sets of surface current measurements made with drift pole over 24-hour periods by the Tides and Currents Survey section of the Canadian Hydrographic Service in the inland seaways (Douglas Channel, Hiekish Narrows, Perceval Narrows, Nawhitti Bar and Cape Scott area). Figure 3 shows representative sites where current measurements have been made in the region. The long series of measurements in the inland seaways such as Douglas Channel and Burke Channel (Webster, 1979a; Webster and Ford, 1979) although shown in Table 5 are not indicated in Figure 3. Some of these measurements made in Douglas Channel during 1977-1978 constitute the longest series (nine months) ever made in the region. Observations made in Queen Charlotte Sound during 1977 by IOS are still being processed (Thomson and Huggett, 1980). Their data will be available shortly (Huggett, et al, 1980).

Wave measurements

There is a total of nine sites from which wave measurements were made in the region. Four of these are in harbours, Prince Rupert (two locations), Kincolith (mouth of Nass River) and Kitimat (head of Douglas Channel). The others are in the open areas of Hecate Strait (Table 6, Figure 3). The observations in the harbours were made over extended periods, from 96 to 355 days during 1972-1978 by the Wave Climate Study group (Marine Environmental Data Service, 1978). The remainder were made by Defence Research Establishment Pacific from the floating drilling rig SEDCO-135F during selected periods in 1968-1969 (Hafer, 1970). Because the data from the drilling rig were for selected periods only, their data do not necessarily represent typical wave data for the region. No winter data is available for the region but measurements made on the continental shelf off Vancouver Island during winter by the drilling rig indicate that the significant wave height can be as large as approximately 8m there. It is probable that waves of such magnitude can be expected in the region also during the winter months.

All of the wave data mentioned above are archived at MEDS and IOS.

Specialized observations

Time series temperature measurements at 2-30 minutes interval have been made from 11 depths in the upper 50 m of water at three sites in Douglas Channel and vicinity during 1977-1978. At two of the three stations there are, except for lack of observations during January and February, one whole year of records available (Table 7). These represent the only extensive time series of measurements of its kind, in the region. The data are kept on file at IOS.

Concluding Remarks

The present inventory of oceanographic data in the Queen Charlotte Sound, Hecate Strait, Dixon Entrance and their vicinity contains data that already have been archived and are readily available, as well as those that are currently being processed and likely will not be available until later. There are also important sets of data for the 600 hydrographic stations taken in Chatham Sound - Dixon Entrance that are still in the original field data log sheets and not even available as summary data record. An attempt has been made to indicate what shape the data are in and where they may be obtained. There may be some inadvertent omissions as some data may still be buried in some investigator's file, but this is unlikely to have much impact on the completeness of this inventory.

The bibliography contains not only references as to the data sources and studies based on them but also those papers and reports that contain information relevant to the oceanography of the region.

Acknowledgements

I wish to acknowledge Dr. M. Waldichuk and Mr. A.J. Dodimead of the Pacific Biological Station; Mr. C.J. Glennie of the Marine Environmental Data Service; Dr. R.E. Thomson, Messrs. R.H. Herlinveaux and M.J. Woodward of the Institute of Ocean Sciences and Mr. I. Webster of Dobrocky SEATECH Ltd. for providing various information related to oceanographic data collected in the region and to Ms. P.M. Kimber and Mr. B.M. Watt for preparing the illustrations.

Bibliography

Data sources

Butler, T.H. and M.S. Smith. 1968. Shrimp sampling and temperature data obtained during exploratory fishing off British Columbia, 1966 and 1967. Fish. Res. Bd. Can. Tech. Rep. 61: 92 p.

Canadian Hydrographic Service. 1979a. Water levels, tidal highs and lows, 1978. Dept. Fish. and Oceans, Ottawa: 215 p.

Canadian Hydrographic Service. 1979b. Water levels, daily means, 1978. Dept. Fish. and Oceans, Ottawa: 130 p.

Canadian Oceanographic Data Centre. 1968. Observations of seawater temperature and salinity on the Pacific coast of Canada, 1966. Dept. Energy, Mines and Resources, 1968 Data record series No. 8, Ottawa: 100 p.

Crean, P.B., W.R. Harling, R.B. Tripp, F.W. Dobson, J.H. Meikle, H.J. Hollister. 1961. Oceanographic data record, Monitor Project, July 24 to November 16, 1961. Fish. Res. Bd. Can. MS Rep. (Oceanogr. Limnol.) 111: 409 p.

Crean, P.B., R.B. Tripp, H.J. Hollister. 1962a. Oceanographic data record, Monitor Project, January 15 to February 5, 1962. Fish. Res. Bd. Can. MS Rep. (Oceanogr. Limnol). 113: 169 p.

Crean, P.B., R.B. Tripp, H.J. Hollister. 1962b. Oceanographic data record, Monitor Project, March 12 to April 5, 1962. Fish. Res. Bd. Can. MS Rep. (Oceanogr. Limnol.) 129: 210 p.

Crean, P.B., H.H. Dobson, H.J. Hollister. 1962c. Oceanographic data record, Monitor Project, September 19 to October 9, 1962. Fish. Res. Bd. Can. MS Rep. (Oceanogr. Limnol.) 142: 203 p.

Davenport, D., M.S. Smith, U.B.G. Kristiansen, J.E. Peters and S.J. Westrheim. 1971. *G.B. Reed* Groundfish cruise No. 71-1, June 9 to 29, 1971. Fish. Res. Bd. Can. Tech. Rep. 269: 27 p.

Department of the Environment, 1972. Harmonic constants and associated data for Canadian tidal waters, Volume 6, Barkley Sound and Discovery Passage to Dixon Entrance. Unpublished manuscript, Tides and Water Levels, Dept. Fish. and Oceans, Ottawa: 166 p.

Dodimead, A.J. 1980a. Data record, Ocean-coastal survey. 11 Sept. - 5 Oct. 1967. Unpublished data, Pacific Biological Station, Nanaimo: data report in preparation.

1980b. Data Record, Ocean-coastal survey, 16-27 April 1968. Unpublished data, Pacific Biological Station, Nanaimo: data report in preparation.

Dodimead, A.J. 1980c. Data record, Odean-coastal survey, 30 Sept. - 16 Oct. 1968. Unpublished data, Pacific Biological Station, Nanaimo: data report in preparation.

1980d. Data record, Ocean-coastal survey, 15-30 April 1969. Unpublished data, Pacific Biological Station, Nanaimo: data report in preparation.

1980e. Data record, Ocean-coastal survey, 1-16 Oct. 1969. Unpublished data, Pacific Biological Station, Nanaimo: data report in preparation.

1980f. Data record, Ocean-coastal survey, 5-15 March 1970. Unpublished data, Pacific Biological Station, Nanaimo: data report in preparation.

1980g. Data record, Ocean-coastal survey, 5-21 March 1971. Unpublished data, Pacific Biological Station, Nanaimo: data report in preparation.

Dodimead, A.J., K.B. Abbott-Smith and H.J. Hollister. 1960c. Oceanographic data record, North Pacific Survey, January 12 to February 10, 1960. Fish. Res. Bd. Can., M.S. Rep. (Oceanogr. and Limnol.) 63: 136 p.

Dodimead, A.J., L.F. Giovando, R.H. Herlinveaux, R.K. Lane, and H.J. Hollister. 1960b. Oceanographic data record, North Pacific Surveys, July 10 to September 6, 1960. Fish. Res. Bd. Can., M.S. Rep. (Oceanogr. and Limnol.), 82: 329 p.

Dodimead, A.J., F.M. Boyce, N.K. Chippindale, H.J. Hollister. 1961. Oceanographic data record, North Pacific Surveys, May 16 to July 1, 1961. Fish. Res. Bd. Can., M.S. Rep. (Oceanogr. and Limnol.) 101: 337 p.

Dodimead, A.J., F.W. Dobson, N.K. Chippindale, H.J. Hollister. 1962. Oceanographic data record, North Pacific Survey, May 23 to July 5, 1962. Fish. Res. Bd. Can., M.S. Rep. (Oceanogr. and Limnol.) 138: 384 p.

Dodimead, A.J., A. Ballantyne and M. Douglas. 1979a. Oceanographic observations during fisheries research surveys off the British Columbia coast in 1977. Fish. and Mar. Serv. Data Rep. 144: 41 p.

Dodimead, A.J. 1979b. Oceanographic observations during fisheries research surveys off the British Columbia coast in 1978. Fish. and Mar. Serv. Data Rep. 160: 136 p.

Dodimead, A.J. and A. Ballantyne. 1980. Oceanographic observations during fisheries research surveys off the British Columbia coast in 1979. Can. Data Rep. of Fisheries and Aquatic Sciences. 210: 90 p.

Giovando, L.F. 1980. Observations of seawater temperature and salinity at British Columbia shore stations 1977. Institute of Ocean Sciences Pacific Marine Science Rep. 80-1, Sidney: 111 p.

Harling, W.R., D. Davenport, L.E. McLeod and S.J. Westrheim. 1968. *G.B. Reed* groundfish cruise, No. 68-2, April 2 to June 11, 1968. Fish. Res. Bd. Can. Can. Tech. Rep. 81: 63 p.

Harling, W.R., D. Davenport, M.S. Smith and B.M. Wilson. 1969. *G.B. Reed* groundfish cruise No. 69-3, Sept. 8 to 25, 1969. Fish. Res. Bd. Can. Tech. Rep. 144: 35 p.

Harling, W.R., D. Davenport, M.S. Smith, U. Kristiansen, and S.J. Westrheim. 1970a. *G.B. Reed* groundfish cruise No. 70-1, March 5 - June 18, 1970. Fish. Res. Bd. Can. Tech. Rep. 205: 82 p.

Harling, W.R., D. Davenport, M.S. Smith and R.M. Wowchuk. 1960b. *G.B. Reed* groundfish cruise No. 70-3, September 9 to 25, 1970. Fish. Res. Bd. Can. Tech. Rep. 221: 35 p.

Harling, W.R., D. Davenport, M.S. Smith, R.M. Wowchuk, and S.J. Westrheim. 1971. *G.B. Reed* groundfish cruise No. 71-3, October 1-29, 1971. Fish. Res. Bd. Can. Tech. Rep. 290: 35 p.

Harling, W.R., D. Davenport, and S.J. Westrheim. 1967. *G.B. Reed* groundfish cruise No. 67-1, February 1 - April 24, 1967. Fish. Res. Bd. Can. Tech. Rep. 22: 56 p.

Herlinveaux, R.H. 1961. Data record of oceanographic observations made in Pacific Naval Laboratory underwater sound studies, 1961. Fish. Res. Bd. Can. M.S. Rep. (Oceanogr. Limnol.) 108: 85 p.

Herlinveaux, R.H. 1963. Data record of oceanographic observations made in Pacific Naval Laboratory underwater sound studies, November 1961 to November 1962. Fish. Res. Bd. Can. M.S. Rep. (Oceanogr. Limnol.) 146: 101 p.

Herlinveaux, R.H. 1967. Drift card releases and recoveries in Burke Channel, British Columbia, 1967. Fish. Res. Bd. Can. M.S. Rep. 970: 17 p.

Herlinveaux, R.H. 1980. Current measurements from drilling rig *SEDCO 135F* off the coast of British Columbia, 1968. Unpublished data, Institute of Ocean Sciences, Sidney: data report in preparation.

Hollister, H.J. 1964. Observations of seawater temperature and salinity at British Columbia coastal stations, Volume 23, 1963, Fish. Res. Bd. Can. M.S. Rep. (Oceanogr. Limnol.) 160: 79 p.

Hollister, H.J. and A.M. Sandnes, 1962. Sea surface temperatures and salinities at shore stations on the British Columbia coast, 1914-1970. Environment Canada, Pacific Marine Science Rep. 72-13, Victoria: 93 p.

Huggett, W.S., R.E. Thomson and M.J. Woodward. 1980. Current observations in Queen Charlotte Sound, Hecate Strait and Queen Charlotte Strait. Unpublished data, Institute of Ocean Sciences, Sidney: data report in preparation.

Institute of Oceanography of the University of British Columbia.

1953. Data Report 1. British Columbia Inlet Study, 1951. Vancouver: 79 p.

1955. Data Report No. 4. CGMV *Cancolim II* Survey of British Columbia coast, 1953. Vancouver: 72 p.

1956. Data Report 8. British Columbia Inlet Cruises, 1954. Vancouver: 33 p.

1962. Data Report No. 20. Sediment grain size analyses, 1960-61. Vancouver: 12 p.

1963a. Data Report No. 21. British Columbia Inlet Cruises, 1962. Vancouver: 90 p.

1963b. Data Report No. 22. Sediment grain-size analyses, 1951, 1960, 1962. Vancouver: 6 p.

1964. Data Report No. 23. British Columbia Inlet Cruises, 1963. Vancouver: 102 p.

1965. Data Report No. 24. British Columbia and Alaska Inlet Cruises, 1964. Vancouver: 34 p.

1966. Data Report No. 25. British Columbia and Alaska Inlet Cruises, 1965. Vancouver: 39 p.

1967. Data Report No. 26. British Columbia and Alaska Inlet Cruises, 1966. Vancouver: 40 p.

1969. Data Report No. 28. British Columbia Inlet Cruises, 1968. Vancouver: 59 p.

1970. Data Report No. 30. British Columbia Inlets and Pacific Cruises, 1969. Vancouver: 65 p.

1971. Data Report No. 32. British Columbia Inlet and Pacific Cruises, 1970. Vancouver: 58 p.

1972. Data Report No. 33. British Columbia Inlet and Pacific Cruises, 1971. Vancouver: 68 p.

1973. Data Report No. 34. British Columbia Inlet and Pacific Cruises, 1972. Vancouver: 48 p.

1974. Data Report No. 35. British Columbia Inlet Cruises, 1973. Vancouver: 127 p.

Joint Committee on Oceanography. 1955a. Data record. Current measurements, Hecate Project, 1954. Pacific Oceanographic Group, Nanaimo: 74 p.

Joint Committee on Oceanography, 1955b. Physical and chemical data record, Hecate Project with Appendix I, Current observations, 1955, Queen Charlotte Sound, Hecate Strait, Dixon Entrance. Pacific Oceanographic Group, Nanaimo: 107 p.

Joint Committee on Oceanography. 1956. Physical and chemical data record: Dixon Entrance, Hecate Strait, Queen Charlotte Sound, 1934, 1937, 1938, 1951. Pacific Oceanographic Group, Nanaimo: 56 p.

Lane, R.K., R.H. Herlinveaux, W.R. Harling, H.J. Hollister. 1960. Oceanographic data record, Coastal and Seaways Projects, October 3-26, 1960. Fish. Res. Bd. Can., M.S. rep. (Oceanogr. Limnol.) 83: 142 p.

Lane, R.K., J. Butters, W. Atkinson, H.J. Hollister. 1961a. Oceanographic data record, Coastal and Seaways Projects, February 6 to March 2, 1961. Fish. Res. Bd. Can. M.S. Rep. (Oceanogr. Limnol.) 91: 128 p.

Lane, R.K., A.M. Holler, J.H. Meikle, H.J. Hollister. 1961b. Oceanographic data record, Monitor and Coastal Projects, March 20 - April 14, 1961. Fish. Res. Bd. Can. M.S. rep. (Oceanogr. Limnol.) 94: 188 p.

Levings, C.D. 1968. Report on groundfish cruise of *G.B. Reed* to Hecate Strait in February 1968. Fish. Res. Bd. Can. Tech. Rep. 62: 41 p.

Macdonald, R.W., D.M. Macdonald and P.S. Munro. 1978. Oceanographic data report, Kitimat Arm, Porpoise Harbour. February 1977. Institute of Ocean Sciences, Sidney: Pacific Marine Science Rep. 78-24. 61 p.

Macdonald, R.W., C.S. Wong, W.J. Cretney and P.E. Erickson. 1980. Chemical data from Kitimat and its seaward approaches. Unpublished data, Institute of Ocean Sciences, Sidney: data report in preparation.

Marine Environmental Data Service. 1978. A summary of available wave data products. Unpublished manuscript, Fisheries and Marine Service, Environment Canada, Ottawa: 28 p.

Pacific Oceanographic Group. 1948. Data report, Chatham Sound, 1948. Unpublished data on file at Institute of Ocean Sciences, Victoria.

Scripps Institution of Oceanography of the University of California. 1960. Oceanic observations of the Pacific: 1950. Berkeley and Los Angeles: Univ. California Press: 508 p.

Scripps Institution of Oceanography of the University of California, 1961 Oceanic observations of the Pacific: Pre-1949. University of California Press, Berkeley and Los Angeles: 349 p.

Scripps Institution of Oceanography of the University of California, 1965a. Oceanic Observations of the Pacific: 1957. Berkeley and Los Angeles, University of California Press: 707 p.

Scripps Institution of Oceanography of the University of California, 1965b. Oceanic observations of the Pacific: 1958. Berkeley and Los Angeles, University of California Press: 804 p.

Scripps Institution of Oceanography of the University of California, 1965c. Oceanic observations of the Pacific: 1959. Berkeley and Los Angeles, University of California Press: 901 p.

Thomson, R.E. and W.S. Huggett. 1980. Oceanographic observations in Queen Charlotte Sound - Hecate Strait, 1977. Unpublished data, Institute of Ocean Sciences, Sidney: data report in preparation.

Waldichuk, J., J.R. Markert and J.H. Meikle. 1968. Physical and chemical oceanographic data from the west coast of Vancouver Island and Northern British Columbia Coast, 1957-1967. Volume II, Fisher Channel - Cousins Inlet, Douglas Channel - Kitimat Arm and Prince Rupert Harbour and its contiguous waters. Fish. Res. Bd. Can. M.S. Rep. 990: 303 p.

Webster, I., 1979a. Kitimat Physical oceanography study, 1977-1978. Data collection and analyses. Dobrocky SEATECH Ltd., Victoria, B.C.: 51 p.

Webster, I. and L. Ford, 1979. Kitimat physical oceanographic study, 1977-1978. A manual for general data access. Dobrocky SEATECH Ltd., Victoria, B.C.: 110 p.

Westrheim, S.J. 1967. *G.B. Reed* groundfish cruise reports, 1963-1966. Fish. Res. Bd. Can. Tech. Rep. 30: 288 p.

Westrheim, S.J., D. Davenport, W.R. Harling, M.S. Smith, and R.M. Wowchuk. 1969a. *G.B. Reed* groundfish cruise No. 69-1, February 11-27, 1969. Fish. Res. Bd. Can. Tech. Rep. 113. 23 p.

Westrheim, S.J., D. Davenport, M.S. Smith, and D. Bianchen. 1969b. *G.B. Reed* groundfish cruise No. 69-2, June 18 - July 2, 1969. Fish. Res. Bd. Can. Tech. Rep. 132. 8 p.

Westrheim, S.J. C.W. Haegele, U.B.G. Kristiansen, and H.A. Webb. 1970. *G.B. Reed* groundfish cruise No. 70-2, August 7-20, 1970. Fish. Res. Bd. Can. Tech. Rep. 210. 15 p.

Westrheim, S.J., W.R. Harling, and D. Davenport. 1968. *G.B. Reed* groundfish cruise No. 66-2, September 6 to October 4, 1967. Fish. Res. Bd. Can. Tech. Rep. 46. 45 p.

Westrheim, S.J., M.S. Smith, W.R. Harling, U.B.G. Kristiansen, and J.E. Peters. 1971. *G.B. Reed* groundfish cruise No. 71-2, August 5 to September 2, 1971. Fish. Res. Bd. Can. Tech. Rep. 278. 15 p.

Reports and papers

Antia, N.J., K. Stephens, R.B. Tripp, T.R. Parsons, J.H.D. Strickland. 1962. A data record of productivity measurements made during 1961 and 1962. Fish. Res. Bd. Can., M.S. Rep. (Oceanogr. Limnol.) 135: 39 p.

Associated Engineering Services Ltd. (P.Y.K. Chang). 1977. Analysis of lighthouse oceanographic data-Phase III. Institute of Ocean Sciences, Contract Rep. Series 77-5, Sidney: 45 p. and 2 Appendices.

Barber, F.G. 1957a. Observations of currents north of Triangle Island, B.C. Fish. Res. Bd. Can. Prog. Rep. Pacific coast stations, No. 108: 15-18.

Barber, F.G. 1957b. The effect of the prevailing winds on the inshore water masses of the Hecate Strait region, B.C., J. Fish. Res. Bd. Can., 14: 945-952.

Barber, F.G. 1958a. On the dissolved oxygen content of the waters of the Hecate Strait region, B.C. Fish.. Res. Bd. Can. Prog. Rep. Pacific Coast Station No. 110: 3-5.

Barber, F.G. 1958b. Currents and water structure in Queen Charlotte Sound, British Columbia. Proc. Ninth. Pac. Sci. Congress of the Pac. Sci. Assn., Vol. 16: 196-199.

Barber, F.G. and S. Tabata. 1954. The Hecate oceanographic project. Fish. Res. Bd. Can. Prog. Rep. Pacific Coast Stations No. 101: 20-22.

Barber, F.G. and A.W. Groll. 1955. Current observations in Hecate Strait. Fish. Res. Bd. Can. Prog. Rep. Pacific Coast Stations No. 103: 23-25.

Bell, W.H. 1963. Surface current studies in the Hecate Model. Fish. Res. Bd. Can. M.S. Rep. (Oceanogr. Limnol.) 159: 27 p.

Bell, W.H. and N. Boston. 1962. The Hecate Model. Fish. Res. Bd. Can. M.S. Rep. (Oceanogr. Limnol.), No. 110: 35 p.

Bell, W.H. and N. Boston. 1963. Tidal calibration of the Hecate Model. J. Fish. Res. Bd. Can., 20: 1197-1212.

Cameron, W.M. 1948. Fresh water in Chatham Sound. Fish. Res. Bd. Can. Prog. Rep. Pacific coast stations No. 76: 72-75.

Cameron, W.M. 1951. Transverse forces in a British Columbia inlet. Trans. Roy. Soc. Can., Sect. V, 45 (Series III): 1-8.

Chang, P., S. Pond and S. Tabata. 1976. Subsurface currents in the Strait of Georgia, west of Sturgeon Bank. J. Fish. Res. Bd. Can., 33: 2218-2241.

Crean, P.B. 1967. Physical oceanography of Dixon Entrance, British Columbia. Fish. Res. Bd. Can., Bull. No. 156: 66 p.

Dodimead, A.J. 1980. A general review of the oceanography of the Queen Charlotte Sound - Hecate Strait - Dixon Entrance region. In preparation for submission to Can. M.S. Rep. Fish. Aquatic Sciences.

Dodimead, A.J. and G.L. Pickard. 1967. Annual changes in the Oceanic-coastal waters of the eastern Subarctic Pacific. J. Fish. Res. Bd. Can., 24: 2207-2227.

Dodimead, A.J. and R.H. Herlinveaux. 1968. Some oceanographic features of the waters of the central British Columbia coast. Fish. Res. Bd. Can., Tech. Rep. 70: 20 p., 107 figures.

Green, D.R., C. Bawden, W.J. Cretney and C.S. Wong. 1974. The Alert Bay oil spill: a one-year study of the recovery of a contaminated bay. Institute of Ocean Sciences Patricia Bay, Pacific Marine Science Rep., 74-9, Victoria: 42 p.

Groves, G.W. 1957. Day to day variation of sea level. Meteorol. Monographs, Vol. 2, No. 10: 32-45.

Hafer, R.A., 1970. Wave measurements from the drilling rig *SEDCO 135F* of the coast of British Columbia. Defence Research Establishment Pacific, Rep. 70-3, 111 p. with Appendix A Wave measuring equipment and Appendix B wave record analysis.

Herlinveaux, R.H., 1957. On tidal currents and properties of the sea water along the British Columbia coast. Fish. Res. Bd. Can. Prog. Re. Pacific coast stations, No. 108: 7-9.

Herlinveaux, R.H. 1973a. Surface water movements in several central British Columbia estuarine systems: North Bentinck Arm, South Bentinck Arm, Burke Channel, Labouchere Channel, Fisher Channel. M.S. Rep., Environment Canada, Marine Sciences Directorate, Pacific Region, Victoria: 71 p.

Herlinveaux, R.H. 1973b. Oceanographic study of the Burke Channel estuary, 1966-1967. M.S. Rep., Environment Canada, Marine Sciences Directorate, Pacific Region, Victoria: 30 p., 72 figures.

Hollister, H.J. 1960. Classifications of daily observations of seawater temperature and salinity on the Pacific coast of Canada, 1915-1959. Fish. Res. Bd. Can. M.S. Rep. (Oceanogr. Limnol.) 68: 139 p.

Hollister, H.J. 1964. Classification of monthly mean sea surface temperatures and salinities at shore stations along the British Columbia and adjacent American coasts, 1915-1962. Fish. Res. Bd. Can. M.S. Rep. (Oceanogr. Limnol.) 177: 123 p.

Hoos, L.M. 1975. The Skeena River estuary. Status of environmental knowledge to 1975. Rep. of the Estuary working group, Dept. of the Environment, Regional Board Pacific Region, Special Estuary Series No. 3, Vancouver: 418 p.

Ketchen, K.S. 1956. Climatic trends and fluctuations in yield of marine fishes of the North Pacific. J. Fish. Res. Bd. Can., 13: 357-374.

Ketchen, K.S. 1956b. Factors influencing the survival of the lemon sole (*Parophrys Vetulus*) in Hecate Strait, British Columbia. J. Fish. Res. Bd. Can., 13: 647-694.

Mackay, B.S. 1953. Tidal current observations in Hecate Strait. J. Fish. Res. Bd. Can., 11: 48-56.

Murty, T.S. and R.E. Brown. 1979. The submarine slide of 27 April,1975 in Kitimat Inlet and the water waves that accompanied the slide. Institute of Ocean Sciences Patricia Bay: Pacific Marine Science Rep. 79-11: Sidney: 36 p.

Narayanan, S. 1979. Kitimat physical oceanographic study, 1977-1978, Tidal circulation model. Dobrocky SEATECH Ltd., Victoria: 62 p.

Parsons, T.R. 1965. A general description of some factors governing primary production in the Strait of Georgia, Hecate Strait and Queen Charlotte Soudn, and the N.E. Pacific Ocean. Fish. Res. Bd. Can. M.S. Rep. (Oceanogr. Limnol.) 193: 52 p.

Pickard, G.L. 1955. British Columbia inlets. Trans. Amer. Geophy. Union. 36: 897-901.

Pickard, G.L. 1961. Oceanographic features of inlets in the British Columbia mainland coast. J. Fish. Res. Bd. Can., 18: 907-999.

Pickard, G.L. 1967. Some oceanographic characteristics of the larger inlets of southeast Alaska. J. Fish. Res. Bd. Can., 24: 1475-1506.

Pickard, G.L. and S. McLeod. 1953. Seasonal variation of temperature and salinity of surface waters of the British Columbia coast. J. Fish. Res. Bd. Can., 10: 125-145.

Pickard, G.L. and R.W. Trites. 1957. Fresh water transport determination from the heat budget with applications to British Columbia inlets. J. Fish. Res. Bd. Can., 14: 606-616.

Robinson, M.K. 1961. The use of a common reference period for evaluating climatic coherence in temperature and salinity records from Alaska to California. Cal. Fish and Game Comm., Report of Cal. Coop. Fish. Investigations, 8: 121-130.

Roden, G.I. 1960. On the nonseasonal variations in sea level along the west coast of North America. J. Geophys. Res., 65: 2809-2826.

Roden, G.I. 1961. On nonseasonal temperature and salinity variations along the west coast of the United States and Canada. Cal. Fish and Game Comm., Rep. of Cal. Coop. Fish. Investigations. 8: 95-119.

Saur, J.F.T. 1962. The variability of monthly mean sea level at six stations in the eastern north Pacific Ocean. J. Geophys. Res., 67: 2781-2790.

Seakem Oceanography Ltd., 1979a. Hydrocarbon levels in the marine environment of Kitimat Arm and its seaward approaches. Victoria: 308 p.

Seakem Oceanography Ltd., 1979b. Kitimat hydrocarbon baseline study: oceanographic observations. Victoria: 96 p.

Stewart, H.B., Jr., B.D. Zetler and C.B. Taylor. 1958. Recent increases in coastal water temperature and sea level - California to Alaska. U.S. Dept. Commerce, Coast and Geodetic Survey, Tech. Bull. No. 3: 11 p.

Tabata, S. 1957. Classification of daily sea-water data. Trans. Amer. Geophy. Union, 38: 191-197.

Tabata, S. 1958: Heat budget of the water in the vicinity of Triple Island, British Columbia. J. Fish. Res. Bd. Can., 15: 429-451.

Tabata, S. 1958. Heat exchange between sea and atmosphere along the northern British Columbia coast. Fish. Res. Bd. Can. Prog. Rep. Pacific coast stations. No. 108: 18-20.

Tabata, S., J.A. Stickland and B.R. de Lange Boom. 1971. The program of current velocity and water temperature observations from moored instruments in the Strait of Georgia - 1968-1970 and examples of records obtained. Fish. Res. Bd. Can. Tech. Rep. 253: 222 p.

Tabata, S. and P.M. Kimber. 1979. Satellite observations of sea surface temperature patterns off the Pacific coast of Canada. Institute of Ocean Sciences, Patricia Bay. Pacific Marine Science Rep. 79-19, Sidney: 77 p.

Thompson, W.F. and R. van Cleve. 1936. Currents of the North Pacific. Life history of the Pacific halibut. Report of the International Fisheries Commission, No. 9: 50-61.

Thompson, W.F. and R. van Cleve. 1936. Drift bottle experiments. Appendix B. Life history of the Pacific halibut. Report of the International Fisheries Commission, No. 9: 161-184.

Thomson, R.E. 1976. Tidal currents and estuarine-type circulation in Johnstone Strait, British Columbia. J. Fish. Res. Bd. Can., 33: 2242-2264.

Trites, R.W. 1956. The oceanography of Chatham Sound, British Columbia. J. Fish. Res. Bd. Can. 13: 385-434.

Tully, J.P. 1952. Daily seawater observations. Joint Committee on Oceanography, Pacific Oceanographic Group, Nanaimo: 21 p.

Waldichuk, M. 1959. Effects of pulp and paper mill wastes on the marine environment. Trans. Second seminar on biological problems in water pollution, April 20-24, 1959, U.S. Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati 26, Ohio: 17 p.

Waldichuk, M. 1962a. Some water pollution problems connected with the disposal of pulp mill wastes. Canadian Fish Culturist, No. 31: 3-34.

Waldichuk, M. 1962b. Observations in marine waters of the Prince Rupert area, particularly with reference to pollution from the sulphite pulp mill on Watson Island, September 1961. Fish. Res. Bd. Can. M.S. Rep. Ser. (Biological). 733: 32 p.

Waldichuk, M. 1962c. Amphipods in low-oxygen marine waters adjacent to a sulphite pulp mill. J. Fish. Res. Bd. Can., 19: 1163-1165.

Waldichuk, M. 1966. Effects of sulfite wastes in a partially enclosed marine system in British Columbia. J. Water Pollution Control Federation, 38: 1484-1505.

Waldichuk, M. 1974. Application of oceanographic information to the design of sewer and industrial waste outfalls. Rapp. P.-v. Réun. Cons. int. Explor. Mer, 167: 236-259.

Webster, I. and D.M. Farmer. 1976. Analysis of salinity and temperature records taken at three lighthouse stations on the B.C. coast. Institute of Ocean Sciences Patricia Bay, Pacific Marine Science Rep. 76-11, Victoria: 42 p.

Webster, I. and D.M. Farmer. 1977. Analysis of lighthouse station temperature and salinity data, Phase II. Institute of Ocean Sciences Patricia Bay, Pacific Marine Science Rep. 77-21, Sidney: 93 p.

Webster, I. 1979b. Kitimat physical oceanographic study, 1977-1978, estuarine circulation. Dobrocky SEATECH Ltd., Victoria: 81 p.

Webster, I. 1979c. Kitimat physical oceanographic study, 1977-1978, Temporal variations of the baroclinic tide in Douglas Channel. Dobrocky SEATECH Ltd., Victoria: 36 p.

Wickett, W.P. 1973. An unusually strong current in Hecate Strait, September 1968. Fish. Res. Bd. Can. Tech. Rep. 395: 23 p.

Figure 1 Chart of Pacific coast of Canada showing Queen Charlotte Sound, Hecate Strait, Dixon Entrance and adjacent coastal seaways and channels. The shaded portion represents oceanographic areas covered in this report.

Figure 2 Chart indicating location of coastal stations making daily surface oceanographic observations (denoted by ⊙) and tidal height measurements (denoted by △).

Figure 3 Chart indicating location of current velocity (denoted by △) and wave measurements (denoted by ⊙).

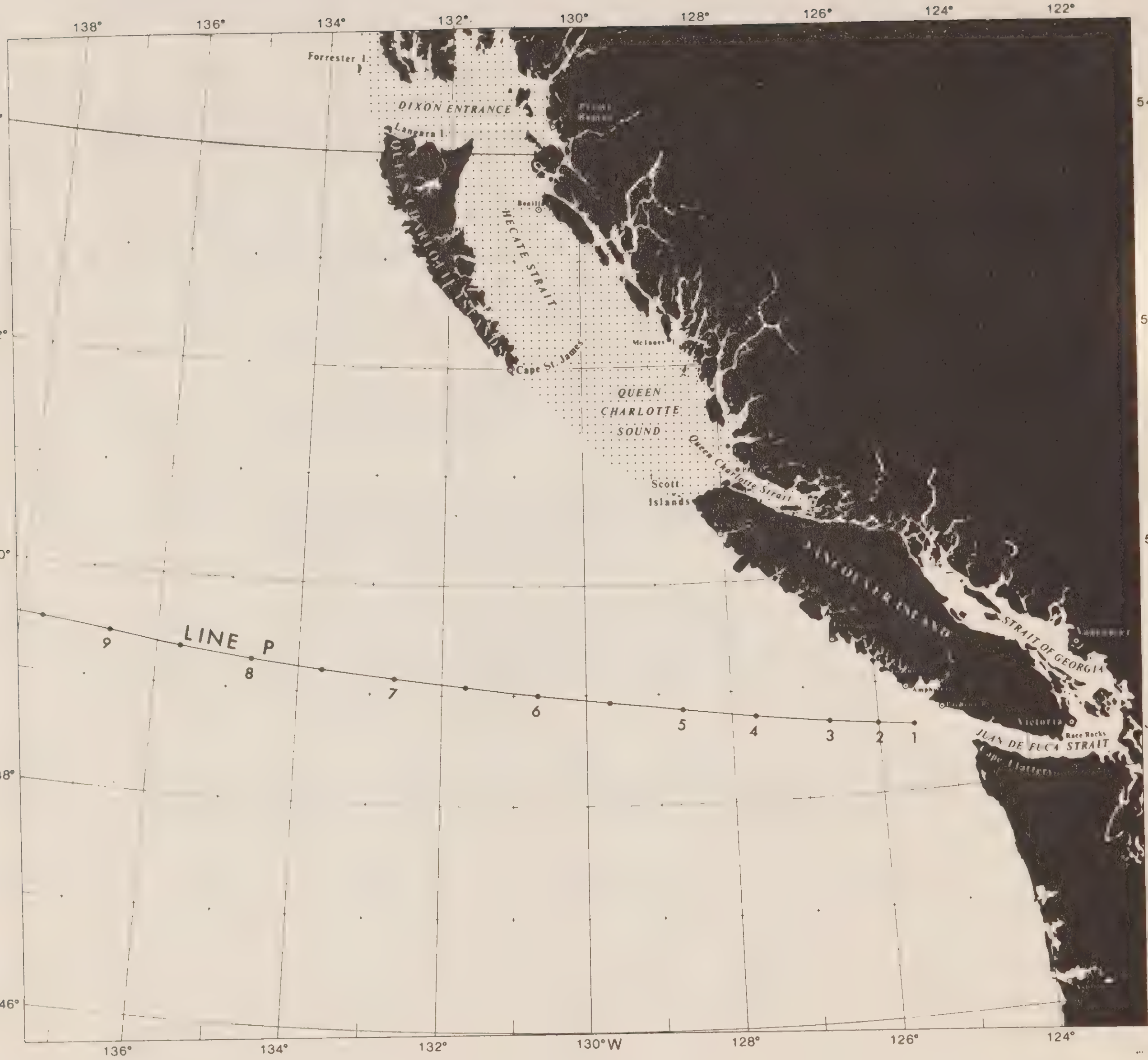

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TABLE 1

List of tidal-height stations, locations and periods of observations in Queen Charlotte Sound - Hecate Strait - Dixon Entrance and adjacent waters.

Station Name	Station Number	Location Lat.N.	Location Long.W.	Period of Observation
(a) Long-Term Records				
Prince Rupert	9354	54°19'	130°20'	May 1906 - Present
Bella Bella	8976	52°10'	128°08'	July 1961 - Present
Kitimat	9140	53°59'	128°42'	April 1977 - Oct 1978
Alert Bay	8280	50°35'	126°56'	July 1947 - Dec 1978
Port Hardy	8408	50°43'	127°29'	June 1964 - Present
Langara Point	9964	54°15'	133°03'	Feb 1973 - Present
Queen Charlotte City	9850	53°15'	132°04'	June 1963 - Present
(b) Short-Term Records				
Lawyer Island	9312	54°08'	130°20'	Aug - Sep 1972
Seabreeze Point	9250	53°59'	130°11'	Aug - 1973
Gillen Harbour	9105	52°58'	129°36'	June - Aug 1977
Port Clements	9920	53°41'	132°10'	July - Aug 1978
Dinan Bay	9930	53°41'	132°36'	Aug 1978
Higgins Passage	9056	52°29'	128°45'	July - Aug 1979
Milne Island	9036	52°37'	128°46'	June - Aug 1979
Smithers Island	9067	52°45'	129°04'	June - July 1979
(c) Special Observations				
Queen Charlotte Sound	Q05 (local designation)	51°22'	130°01'	18 May - 19 July 1977

These observations were made at 15 minute intervals by Aanderaa bottom-mounted pressure recorder.

Note: There are many other special short-term records. These are listed in harmonic constants and associated data for Canadian tidal waters (e.g. Department of the Environment, 1972).

TABLE 1 (Cont.)

(d) Special observations made by Dobrocky SEATECH Ltd.

Green Inlet (mouth)	TG3	52°55.1'	128°29.8'	16 July - 25 Sep 1977 9 Dec 1977 - 9 Mar 1978
Campania Island (North West)	TG4	53°10.4'	129°32.8'	8 July - 26 Sep 1977 26 Sep - 10 Dec 1977
Klewnuggit Inlet (mouth)	TG5	53°40.8'	129°45.6'	11 July - 29 Sep 1977 12 March - 9 June 1978
Kildala Arm (mouth)	TG1	53°52.1'	128°42.1'	27 Sep - 9 Dec 1977 9 March - 10 June 1978
Redfern Point (South)	TG2	53°01.4'	129°11.5'	26 Sep - 7 Dec 1977 13 Dec 1977 - 8 Mar 1978
Coghlan Anchorage	TG6	53°23.0'	126°16.8'	3 Oct - 6 Dec 1977 6 Dec 1977 - 7 Mar 1978 7 Mar - 9 June 1978
Eva Point (North)	TG8	53°35.0'	128°53.5'	11 Dec 1977 - 11 Mar 1978
Owyacumish Bay	TG7	53°29.0'	128°07.3'	11 Mar - 10 June 1978

TABLE 2

Location of shore stations in Queen Charlotte Sound - Hecate Strait - Dixon Entrance and adjacent waters making daily oceanographic observations.

Station	Location		Period of Observation
	Lat.N	Long.W	
Langara Island	54°15'	133°03'	November 1936 - August 1937; March 1940 - Present
Green Island	54°34'	130°42'	February 1935 - August 1936
Prince Rupert	54°19'	130°18'	February 1934 - October 1935; January 1940 - May 1942
Triple Island	54°18'	130°53'	November 1939 - December 1970
Masset	54°01'	132°09'	December 1939 - October 1942
Port Clements	53°41'	132°11'	October 1941 - August 1942
Shannon Bay	53°39'	132°30'	December 1939 - August 1941
Sandspit	53°15'	141°49'	August 1953 - December 1956
Bonilla Island	53°30'	130°38'	April 1960 - Present
McInnes Island	52°16'	128°43'	August 1954 - Present
Ivory Island	52°16'	128°24'	August 1937 - December 1955
Cape St. James	52°56'	131°01'	August 1934 - Present; intermittent observations 1938 - 1942
Egg Island	51°15'	127°50'	March 1970 - Present
Pine Island	50°58'	127°44'	January 1937 - Present

TABLE 3

Hydrographic-station data collected mainly by the Pacific Oceanographic Group (POG) from Queen Charlotte-Hecate Strait-Dixon Entrance and adjacent waters. Most of the data taken since 1967 are with salinity-temperature-depth (STD) or conductivity-temperature-pressure (CTP) recorders.

	Area	No. of Stations	Periods of Observations	References	Remarks
1.	Dixon Entrance	3	3 Sept. 1934	Joint Committee on Oceanography, 1956	Data taken by the University of Washington
2.	Approaches to Queen Charlotte Sound	10	4-5 Sept. 1936	Scripps Institution of Oceanography of the University of California, 1961	Data taken by the Pacific Biological Station
3.	Dixon Entrance	20	25-28 July 1937	Joint Committee on Oceanography, 1956	Data taken by the University of Washington
4.	Dixon Entrance-Hecate Strait	61	24 May - 5 June 1938	"	Data taken by the Pacific Biological Station
5.	Chatham Sound and Dixon Entrance	24	19-21 May 1948	Pacific Oceanographic Group, 1948	Data taken mainly from Chatham Sound in all of this set of data
6.	"	30	25-28 May 1948	"	
7.	"	44	1-4 June 1948	"	
8.	"	85	8-18 June 1948	"	
9.	"	111	21-29 June 1948	"	
10.	"	56	2-7 July 1948	"	Anchor Stns: Stn. 80 for 25 hours Stn. 81 for 24 hours Stn. 82 for 40 hours
11.	"	26	20-22 July 1948	"	
12.	"	15	22-23 July 1948	"	Anchor Stn. 82 for 25 hours

	Area	No. of Stations	Periods of Observations	References	Remarks
13.	Chatham Sound and Dixon Entrance	27	27-30 July 1948	Pacific Oceanographic Group, 1948	
14.	"	45	3-5 August 1948	"	
15.	"	7	7-8 August 1948	"	Anchor Stn.113 for 25 hours
16.	"	91	10-19 August 1948	"	
17.	"	4	24 August 1948	"	Anchor Stn.75 for 12 hours
18.	"	25	30 August - 7 Sept. 1948	"	
19.	"	5	31 August 1948	"	Anchor Stn. 76 for 12 hours
20.	"	27	8-10 Sept. 1948	"	
21.	Approaches to Dixon Entrance	1	12 August 1950	Scripps Institution of Oceanography of the University of California, 1960	
22.	Queen Charlotte Sound-Hecate Strait-Dixon Entrance	35	12-23 May 1951	Joint Committee on Oceangraphy, 1956	
23.	Queen Charlotte Sound and Dixon Entrance	32	22 July - 1 Aug. 1951	"	
24.	Queen Charlotte Sound-Hecate Strait-Dixon Entrance	71	6-13 February 1955	Joint Committee on Oceanography, 1955	
25.	"	64	14-18 April 1955	"	
26.	"	96	8-23 June 1955	"	
27.	Dixon Entrance	4	20-25 February 1957	Scripps Institution of Oceanography of the University of California, 1965a	
28.	Dixon Entrance and Approaches to Queen Charlotte Sound	6	2-11 May 1957	"	

	Area	No. of Stations	Periods of Observations	References	Remarks
29.	Dixon Entrance	1	9 July 1957	Scripps Institution of Oceanography of the University of California, 1965a	
30.	"	1	21 August 1957	"	
31.	Approaches to Queen Charlotte Sound	5	30 Sept. - 1 Oct. 1957	"	
32.	Dixon Entrance and Queen Charlotte Sound	11	2-17 December 1957	"	
33.	Dixon Entrance and approaches to Queen Charlotte Sound	12	15-23 March 1958	Scripps Institution of Oceanography of the University of California, 1965b	
34.	Queen Charlotte Sound-Hecate Strait-Dixon Entrance	7	27 June - 1 July 1958	"	A wide range of chemical properties of water (ph, alkalinity. silicates, phosphates, nitrates, nitrites, iron were observed. This physical data is considered by P.O.G. to be below the usual observational standard.
35.	Approaches to Queen Charlotte Sound	1	14 August 1958	"	
36.	Dixon Entrance and approaches to Queen Charlotte Sound	9	26 July - 1 August 1958	"	
37.	Queen Charlotte Sound-Hecate Strait-Dixon Entrance	35	18-26 November 1958	"	
38.	Dixon Entrance and approaches to Queen Charlotte Sound	6	23-31 January 1959	Scripps Institution of Oceanography of the University of California, 1965c	
39.	Queen Charlotte Sound-Hecate Strait-Dixon Entrance	68	12-19 April 1959	"	
40.	"	50	21-30 June 1959	"	
41.	Queen Charlotte Sound and Dixon Entrance	5	26 August - 1 Sept. 1959	"	

	Area	No. of Stations	Periods of Observations	References	Remarks
42.	Queen Charlotte Sound - Hecate Strait - Dixon Entrance	34	3-10 December 1959	Scripps Institution of Oceanography of the University of California, 1965c	
43.	Dixon Entrance and approaches to Queen Charlotte Sound	8	17-22 January 1960	Dodimead et al, 1960a.	
44.	Dixon Entrance and Queen Charlotte Sound	9	28 Aug. - Sept. 6, 1960	Dodimead et al, 1960b.	
45.	Dixon Entrance and approaches to Queen Charlotte Sound	20	3-14 June 1961	Dodimead et al, 1961.	
46.	Dixon Entrance and approaches to Queen Charlotte Sound	9	8-23 June 1962	Dodimead et al, 1962.	
47.	Queen Charlotte Sound - Hecate Strait - Dixon Entrance	16	20-23 October, 1960	Lane et al, 1960.	
48.	Dixon Entrance and Hecate Strait	21	10-16 February, 1961	Lane et al, 1691a.	
49.	Queen Charlotte Sound	3	12-13 April, 1961	Lane et al, 1961b.	
50.	Queen Charlotte Sound - Hecate Strait - Dixon Entrance	54	27 July - 3 August, 1961	Crean et al, 1961.	
51.	Queen Charlotte Sound - Hecate Strait - Dixon Entrance	89	3-17 October, 1971	"	
52.	Queen Charlotte Sound - Hecate Strait - Dixon Entrance	55	17-24 January, 1962	Crean et al, 1962a.	
53.	Queen Charlotte Sound - Hecate Strait - Dixon Entrance	59	14-20 March, 1962	Crean et al, 1962b.	
54.	Dixon Entrance and Hecate Strait	164	19 Sept. - 9 Oct. 1962	Crean et al, 1962c.	
55.	Dixon Entrance	5	2-3 Sept., 1961	Herlinveaux, 1961	Some of the observations were made by the Scripps Institution of Oceanography.

	Area	No. of Stations	Periods of Observations	References	Remarks
56.	Queen Charlotte Strait	3 4	15 Feb., 1962 22-23 August, 1962	Herlinveaux, 1963 "	
57.	Inlets and waters off Prince Rupert	48	15-21 Sept., 1961	Waldichuk et al, 1968	Observations made by Pacific Biological Station. pH and alkalinity were also observed.
58.	Inlets and waters off Prince Rupert	48	14-26 April 1962	"	"
59.	Inlets and waters off Prince Rupert	48	16-28 Oct., 1964	"	"
60.	Inlets and waters off Prince Rupert	48	10 July- 28 Sept., 1967	"	"
61.	Queen Charlotte Sound - Hecate Strait - Dixon Entrance	56	18-25 Sept. 1967	Dodimead, 1980a	Mostly salinity - temperature - depth (STD) data. Nitrates, silicates & phosphates also observed.
62.	Queen Charlotte Sound	28	25-27 April 1968	Dodimead, 1980b	Mostly STD data.
63.	Queen Charlotte Sound	21	9-12 Oct. 1968	Dodimead, 1980c	"
64.	Queen Charlotte Sound	41	27-30 April, 1969	Dodimead, 1980d	Mostly STD data.
65.	Queen Charlotte Sound	29	1-16 Oct., 1969	Dodimead, 1980e	"
66.	Queen Charlotte Sound	21	5-15 March, 1970	Dodimead, 1980f	Mostly STD data.
67.	Queen Charlotte Sound	29	5-21 March, 1971	Dodimead, 1980g	"
68.	Queen Charlotte Sound	23	16-27 May, 1977	Thompson and Huggett, 1980	Observations made by Institute of Ocean Sciences. Mainly conductivity-temperature-pressure (CTD) data.
69.	Queen Charlotte Sound	23	14-21 July, 1977	"	"
70.	Queen Charlotte Sound	23	20-27 Sept., 1977	"	"

TABLE 4

Hydrographic station data collected by the Institute of Oceanography of the University of British Columbia (IOUBC) mainly from inlets adjacent to Queen Charlotte Sound-Hecate Strait-Dixon Entrance and conductivity-temperature-pressure (CTP) data obtained by Dobrocky SEATECH Limited in Douglas Channel-Gardner Canal area.

	Number of Stations	Periods of Observations	References	Remarks
1.	189	8 June - 31 July 1951	IOUBC, 1953	Observations taken from Seymour Inlet (south) to Portland Canal (north)
2.	111	12-30 June 1953	IOUBC, 1955	Observations taken mainly in Queen Charlotte Strait; 5 anchor stations where 2-hourly observations up to 26 hours were taken
3.	89	16 July - 10 August 1953	IOUBC, 1955	32 of the 89 stations are in Queen Charlotte Sound-Hecate Strait -Dixon Entrance; the next are in the waters adjacent to Queen Charlotte Island; one anchor station for 24 hours in Massett Inlet.
4.	60	14-21 July 1956	IOUBC, 1956	Observations from Rivers Inlet (south) to Finlayson Channel (north)
5.	373	18 February 1960 - 25 Nov. 1961	IOUBC, 1962	Results of analysis on sediments collected from continental shelf, straits and inlets of B.C.; Juan de Fuca Strait (south) to Browning Entrance (north).
6.	14	18-20 May 1962	IOUBC, 1963a	Observation mainly in Belize Inlet.
7.	16	29 June - 9 July 1962	IOUBC, 1963a	Observations mainly in Queen Charlotte Strait
8.	187	12 May - 7 August 1951 31 May 1960 - 9 August 1962	IOUBC, 1963b	Results of analysis on sediments collected from various parts of coastal waters of B.C. from Jervis Inlet; west coast of Vancouver Island (south) to Portland Canal (north).
9.	26	16-19 May 1963	IOUBC, 1964	Observations mainly in Burke and Deam Channels.
10.	18	27-30 June 1963	IOUBC, 1964	Douglas Channel (south) to Portland Inlet (north).
11.	1	5 May 1964	IOUBC, 1965	One station in Queen Charlotte Strait
12.	72	5-10 June 1964	IOUBC, 1965	Observations mainly in Alaskan Inlets; Behm Canal (south) to Icy Strait (north).

	Number of Stations	Periods of Observations	References	Remarks
13.	79	2-14 August 1965	IOUBC, 1966	Observations mainly in Alaskan inlets; Behm Canal (south) to Glacier Bay (north).
14.	48	12-17 May 1966	IOUBC, 1967	Observations at 39 stations in B.C. inlets (Burke Channel -Portland Inlet) and 9 stations in Alaskan waters (Behm Canal)
15.	13	26 - 27 May 1968	IOUBC, 1969	Observations mainly in Seymour and Belize Inlets.
16.	4	14-16 July 1968	IOUBC, 1969	Observations in Queen Charlotte Strait, Queen Charlotte Sound, Seymour and Belize Inlets.
17.	1	5 May 1969	IOUBC, 1970	One station in Queen Charlotte Strait
18.	20	31 May - 3 June 1969	IOUBC, 1970	Observations in Seymour Inlet to Dean Channel
19.	5	23-25 May 1970	IOUBC, 1971	Observations in Queen Charlotte Strait, Queen Charlotte Sound, Seymour and Belize and Smith Inlets
20.	32	20 June - 16 July 1970	IOUBC, 1971	Observations mainly in Burke Channel (south) to Finlayson Channel (north).
21.	2	11 February 1971	IOUBC, 1972	Observations in Queen Charlotte Strait and Smith Inlet.
22.	2	17-18 August 1971	IOUBC, 1972	Observations in Seymour and Belize Inlets.
23.	28	22-26 June 1972	IOUBC, 1973	Observations mainly in Burke Channel (south) to Finlayson Channel (south)
	1	26 July, 1972	IOUBC, 1973	One station in Queen Charlotte Strait.
24.	1	30 August 1972	IOUBC, 1973	One station in Queen Charlotte Strait
25.	1	18 October 1972	IOUBC, 1973	One station in Queen Charlotte Strait.
26.	1	9 February 1973	IOUBC, 1974	One station in Queen Charlotte Strait.
	1	28 February 1973		
27.	1	28 March 1973	IOUBC, 1974	One station in Queen Charlotte Strait.
28.	1	2 May 1973	IOUBC, 1974	One station in Queen Charlotte Strait.
29.	1	26 June 1973	"	One station in Queen Charlotte Strait.
30.	1	19 August 1973	"	One Station in Queen Charlotte Strait.

	Number of Stations	Periods of Observations	References	Remarks
31.	1	23 October 1973	IOUBC, 1974	One station in Queen Charlotte Strait.
32.	1	11 December 1973	IOUBC, 1974	One station in Queen Charlotte Strait.
	Kitimat (Douglas Channel, Gardner Canal, etc.)			
33.	61	8-16 July 1977		CTP data; observations made by Dobrocky SEATECH Ltd. 8 hydrographic stations taken.
34.	87	25 September - 5 October 1977	Webster, 1979a; 1979b	These include 40 stations at anchor stations.
35.	112	5-17 December 1977		These include 56 stations at anchor stations.
36.	115	5-15 March 1978		"
37.	37	8-13 June 1978		"

TABLE 5

Current velocity measurements in Queen Charlotte Sound - Hecate Strait - Dixon Entrance and adjacent waters.

Area	Station Number	Lat.N.	Long.W	Depth (m)	Depth of Observations(m)	Sampling Interval	Period of Observations	Methods of Observations	References	Remarks
Chatham Sound	113	54°13.0'	130°23.4'	51	0,11	1½ hours	7-8 Aug. 1948 (25 hrs)	Free current drags	Trites, 1956	Data unpublished. Unable to locate original current velocity data. The magnitudes of latitude and longitude may not correspond to those of today because the old Admiralty charts were utilized in 1948
" "	75	54°09.4'	130°20.2'	27	0,5,9,18	"	24 Aug. 1948 (12 hrs)	"	"	
" "	76	54°42.3'	130°34.1'	37	0,18	"	31 Aug. 1948 (12 hrs)	"	Cameron, 1951; Trites, 1956	
Hecate Strait	HS-1	54°08'	131°04'	77	0,76	30 mins.	12-27 July 1952	Drift pole, Ekman current meter	Mackay, 1954	Data unpublished. Longest series of uninterrupted data was made during 24-26 July (41 hours).
Hecate Strait	44	53°15.5'	131°30.3'	20	0,5,17,17	1 hour	19-21 May 1954 (50 hrs)	current drag, Ekman current meter	Joint Committee on Oceanography, 1955a Barber, 1955	Hourly wind velocity data at the sites have been published also.
" "	43	53°26.6'	131°04.2'	60	0,10,20,30,50	1 hour	21-23 May 1954 (50 hrs)	"		
" "	42	53°36.3'	130°43.8'	183	0,10,20,30,50 100,150	1 hour	23-25 May 1954 (50 hrs)	"		
Dixon Entrance	65	54°10.5'	132°00.0'	80	0,10,20,30,50 75	1 hour	17-19 1954 (50 hrs)	"		
Hecate Strait	I-3	52°53'	130°08'	234	0,10,20,50, 100,200	1 hour	30 Aug. - 1 Sept. 1954 (50 hrs)	"		
" "	I-2	52°40.0'	130°40.0'	137	0,10,20,30,50, 100	1 hour	2-4 Sept. 1954 (50 hrs)	"		
" "	I-1	52°31.2'	131°07.7'	88	0,10,20,30,50, 75	1 hour	4-6 Sept. 1954 (50 hrs)	"		
" "	6	50°54.7'	128°04.6'	29	0,10,20,25	1 hour	7 Sept. 1954 (14 hrs)	"		

Area	Station Number	Lat.N.	Long.W	Depth (m)	Depth of Observations(m)	Sampling Interval	Period of Observations	Methods of Observations	References	Remarks
Queen Charlotte Sound	6	[illegible].7'	129°06.0'	84	0,10,20,30, 50,75	1 hour	1-3 June 1955 (50 hrs)	Current drag, Ekman current meter	Joint Committee on Oceanography, 1955b; Barber, 1957.	Hourly wind velocity data at the sites have been published also.
" "	14	51°19.7'	128°27.0'	124	0,10,20,30, 50,75,100	1 hour	4-5 June 1955 (25 hrs)	"	Joint Committee on Oceanography, 1955b.	
" "	5	51°01.5'	127°54.8'	132	0,10,20,30,50 75,100,120	1 hour	6-8 June 1955 (50 hrs)	"		
Dixon Entrance	60-61	54°41.0'	131°20.0'	176	0,10,20,30,50, 75,100,150	1 hour	14 June 1955 (6 hrs)	"		
Hecate Strait	26	53°46.0'	131°15.0'	40	0,10,20,30,35	1 hour	15 June 1955 (13 hrs)	"		
Queen Charlotte Strait	T	50°49.5'	127°15.8	60	10,20,30,50	1 hour	6-8 June 1955 (49 hrs)	Ekman current meter		
Dixon Entrance	A	54°33'	132°02'	263	0,50,100,150 200	2 hours	24-26 Sept. 1962 (38 hrs)	Surface drift pole, Ekman current meter	Crean et al 1963; Crean 1967	Meteorological observations including wind velocity made at bi-hourly intervals also. Current velocity data unpublished.
" "	B	54°26'	132°00'	320	0,50,100,150 200	2 hours	1-3 Oct. 1962 (50 hrs)	"		
" "	C	54°17'	132°00'	198	0,50,100,150	2 hours	8-9 Oct. 1962 (25 hrs)	"		
Cousins Inlet	0-10A	52°21.10'	127°42.25'	49	0,5,10,15,20, 30,40	1 hour	25-26 April 1962 (23 hrs)	Chesapeake Bay Institute Drag, Ekman current meter	Waldichuk et al, 1968	Wind velocity data also collected at hourly intervals.

Area	Station Number	Lat.N.	Long.W	Depth (m)	Depth of Observations (m)	Sampling Interval	Period of Observations	Methods of Observations	References	Remarks
Kitimat Harbour	K-9A	53°59.50'	128°40.50'	46	0,5,10,15, 20,30,40	30 mins. at surface. 1 hour elsewhere	17-19 Oct. 1964 (39 hrs)	Chesapeake Bay Drag, Ekman current meter	Waldichuk *et al*, 1968	Wind velocity data also collected at hourly intervals.
Prince Rupert Harbour	P-4A	54°14.00'	130°20.50'	40	0,5,10,15 20,30	"	24-26 Oct. 1964 (39 hrs)	"		
Burke Channel	-	-	-	-	surface	-	20 Apr. - 12 July 1967	Drift cards	Herlinveaux; 1968; 1973a; 1973b.	Some meteorological data are also available.
North Bentinck Arm (Burke Channel)	1N	52°22.4'	126°53.5	230	2	20 mins.	9 April - 1 May 1967 (22 days)	Neyrpic current meter	Herlinveaux; 1973a; 1973b.	Some meteorological data are also available. This series of measurements in Burke Channel and Fisher Channel represents the first attempt to measure current velocities from moored buoys for extended periods (in the region).
"	1S	52°21.8'	126°52.9'	73	"	"	9-11 April 1967 (2 days)	"		
"	1S	"	"	"	"	"	23-26 April 1967 (3 days)	"		
"	1C	52°22.1'	126°53.1'	358	"	"	9-19 April 1967 (10 days)	"		
Burke Channel	2S	52°17.1'	126°58.8'	183	"	"	11-20 April 1967 (9 days)	"		
"	2C	52°17.4'	126°58.0'	543	"	"	11-19 April 1967 (8 days)	"		
	2N	52°17.7'	126°57.3'	183	"	"	11-29 April 1967 (18 days)	"		
"	2S	52°17.1'	126°58.8'	183	"	"	30 April - 17 May 1967 (17 days)	"		
"	2N	52°17.7'	126°57.3'	183	"	"	11-17 May 1967 (6 days)	"		
"	2C	52°17.4'	126°58.0'	543	"	"	15 May 1967 (1 day)	"		

Area	Station Number	Lat. N.	Long. W	Depth (m)	Depth of Observations (m)	Sampling Interval	Period of Observations	Methods of Observations	References	Remarks
South Bentinck Arm (Burke Channel)	3E	52°19.9'	127°06.4'	64	2	20 mins.	29-30 April 1967 (1 day)	Neyrpic current meter	Herlinveaux, 1973a; 1973b.	Some meteorological data are also available. This series of measurements in Burke Channel and Fisher Channel represent the first attempt to measure current velocities from moored buoys for extended period.
"	3C	52°19.4'	127°06.6'	246	"	"	11-12 April 1967 (1 day)	"		
"	3C	"	- "	"	"	"	21 April - 11 May 1967 (20 days)	"		
"	3W	52°18.7'	127°06.8'	183	"	"	30 April - 11 May 1967 (11 days)	"		
Labouchere Channel (Burke Channel)	4W	52°23.9	127°14.3'	91	"	"	5-17 May 1967 (12 days)	"		
"	4C	52°23.7'	127°13.5'	264	"	"	5-17 May 1967 (12 days)	"		
"	4E	52°23.6'	127°12.8'	91	"	"	5-17 May 1967 (12 days)	"		
Burke Channel	5S	52°17.7'	127°12.4'	91	"	"	12-18 May 1967 (6 days)	"		
"	5N	52°18.2'	127°14.1'	183	"	"	12-18 May 1967 (6 days)	"		
"	6C	51°55.6'	127°51.6'	69	"	"	20-27 May 1967 (7 days)	"		
"	6N	51°55.9'	127°52.1'	91	"	"	20 May - 8 June 1967 (19 days)	"		
"	6S	51°55.2'	127°51.1'	128	"	"	20-27 May 1967 (7 days)	"		

Area	Station Number	Lat.N.	Long.W	Depth (m)	Depth of Observations (m)	Sampling Interval	Period of Observations	Methods of Observations	References	Remarks
Fisher Channel	7E	$51^{o}57.0'$	$127^{o}54.7'$	70	2	20 mins.	20 May - 8 June 1967 (19 days)	Neyrpic current meter	Herlinveaux; 1973a; 1973b.	Some meteorclogical data are also available. This series of measurements in Burke Channel and Fisher Channel represent the first attempt to measure current velocities from moored buoys for extended period.
"	7C	$51^{o}56.9'$	$127^{o}56.0'$	344	2	"	20 May - 6 June 1967 (17 days)	" "		
"	7W	$51^{o}56.8'$	$127^{o}57.2'$	183	2	"	20 May - 8 June 1967 (19 days)	" "		
Hecate Strait	N-39 "TYEE"	$53^{o}18.9'$	$131^{o}20.3$	26	4,25	continuous	22-24 April 1968 (2 days	Hydroproducts current meter	Unpublished data	These observations were made from drilling rig SEDCO 135F. Some meteorological data are available. Bottom currents measured at depth 1 m above bottom.
	"	"	"	26	4	20 mins.	24 April - 5 May 1968 (11 days)	"	Herlinveaux, 1980	
	B-10 "SOCKEYE"	$52^{o}49.1'$	$131^{o}00.7'$	60	4,59	continuous	27 May - 1 June 1968 (5 days)	"		Bottom current measured at depth 1 m above bottom.
	"	"	"	"	4	20 mins.	29 May - 12 June 1968 (14 days)	"		
	"	"	"	"	"	"	13-24 June 1968 1968 (11 days)	"		
	"	"	"	"	"	"	26-30 June 1968 1968 (4 days)	"		
	G-41 "AUKLET"	$52^{o}20.3'$	$130^{o}36.5'$	169	75	continuous	20-27 Aug. 1968 (7 days)	"		
	D-86 "HARLEQUIN"	$51^{o}55.1'$	$129^{o}58.2'$	135	75	"	4-13 Oct. 1968 (9 days)	"		
Queen Charlotte Strait	Q01	$50^{o}51.3'$	$127^{o}20.0'$	140	15	15 mins.	30 Jan. - 4 Mar. 1977 (34 days)	Aanderaa current meter	Huggett et al, 1980	Preliminary data; subject to revision. Data summary in preparation. These observations were made from moored buoys. Temperature, conductivity, pressure recorded as well.
"	Q01	"	"	"	"	"	5 March-15 May 1977 (71 days)	"		

Area	Station Number	Lat.N.	Long.W	Depth (m)	Depth of Observations(m)	Sampling Interval	Period of Observations	Methods of Observations	References	Remarks
Queen Charlotte Strait	[illegible]	[illegible]	[illegible]	363	[illegible]	15 mins.	30 Jan. - 4 Mar. 1977 (34 days)	Aanderaa current meter	Huggett et al, 1980	Preliminary data; subject to revision. Data summary in preparation. These observations were made from moored buoys. Temperature conductivity, pressure recorded as well.
"	002	"	"	"	40	"	5 March - 15 May 1977 (71 days)	"		Temperature and pressure recorded.
"	002	"	"	"	75	"	5 March - 15 May 1977 (71 days)	"		Temperature and conductivity recorded.
"	002	"	"	"	85	"	30 Jan. - 4 Mar. 1977 (34 days)	"		Temperature and pressure recorded.
"	002	"	"	"	300	"	30 Jan. - 4 Mar. 1977 (34 days)	"		Temperature, conductivity and pressure recorded.
"	002	"	"	"	315	"	5 March - 15 May 1977 (71 days)	"		"
Queen Charlotte Sound	003	50°58.9'	129°16.9'	159	9	"	15 July - 20 Sept. 1977 (67 days)	"		"
	003	50°58.5'	129°17.6'	159	15	"	18 May - 15 July 1977 (58 days)	"		"
	003	"	"	159	150	"	18 May - 15 July 1977 (58 days)	"		"
	003	50°58.9'	129°16.9'	159	150	"	15 July - 20 Sept. 1977 (67 days)	"		"
	004	51°19.3'	129°01.6'	260	15	"	18 May - 14 July 1977 (57 days)	"		Temperature and conductivity recorded.

Area	Station Number	Lat.N.	Long.W	Depth (m)	Depth of Observations (m)	Sampling Interval	Period of Observations	Methods of Observations	References	Remarks
Queen Charlotte Sound	Q04	$51^{\circ}18.9'$	$129^{\circ}02.0'$	260	15	15 mins.	14 July - 20 Sept. 1977 (68 days)	Aanderaa current meter	Huggett et al, 1980	Temperature and conductivity recorded
	Q04	"	"	260	250	"	14 July - 20 Sept. 1977 (68 days)			Temperature, conductivity and pressure recorded
	Q04	$51^{\circ}19.3'$	$129^{\circ}16.9'$	260	255	"	18 May - 14 July 1977 (57 days)			"
	Q05	$51^{\circ}12.2'$	$130^{\circ}01.0'$	269	9	"	18 May - 19 July 1977 (62 days)			"
	Q05	"	"	269	255	"	18 May - 19 July 1977 (62 days)			Temperature and conductivity recorded
	Q07	$52^{\circ}20.2'$	$130^{\circ}19.5'$	350	10	"	22 May - 17 July 1977 (56 days)			"
	Q07	"	"	350	10	"	17 July - 21 Sept. 1977 (66 days)			"
	Q07	"	"	350	320	"	17 July - 1 Aug. 1977 (15 days)			"
	Q07	"	"	350	345	"	22 May - 17 July 1977 (56 days)			"
	Q08	$52^{\circ}20.9'$	$129^{\circ}29.6'$	164	18	"	19 May - 17 July 1977 (59 days)			Temperature, conductivity and pressure recorded
	Q08	"	"	164	18	"	17 July - 18 Aug. 1977 (32 days)			"
	Q08	$52^{\circ}21.0'$	$129^{\circ}30.0'$	164	160	"	19 May - 17 July 1977 (59 days)			"
	Q08	$52^{\circ}20.9'$	$129^{\circ}29.6'$	164	160	"	17 July - 23 Sept. 1977 (68 days)			"

Area	Station Number	Lat.N.	Long.W	Depth (m)	Depth of Observations(m)	Sampling Interval	Period of Observations	Methods of Observations	References	Remarks
Hecate Strait	H01	53°28.9'	130°46.2'	164	15	15 mins.	21 May - 18 July 1977 (58 days)	Aanderra current meter	Huggett <u>et</u> <u>al</u>, 1980	Temperature and conductivity recorded
"	H01	53°28.8'	130°45.7'	164	15	"	18 July - 24 Sept. 1977 (68 days)	"	"	"
"	H01	53°28.9'	130°46.2'	164	150	"	21 May - 18 July 1977 (58 days)	"	"	"
"	H01	53°28.2'	130°45.7'	164	150	"	18 July - 24 Sept. 1977 (68 days)	"	"	"
"	H02	53°41.3'	130°31.5'	50	17	"	21 May - 18 July 1977 (58 days)	"	"	Temperature, conductivity and pressure recorded
"	H02	"	"	50	17	"	18 July - 12 Aug. 1977 (25 days)	"	"	"
Caamano Sound	CS1	52°52.7'	129°53.8'	188	15	"	20 May - 16 July 1977 (57 days)	"	"	"
"	CS1	52°52.9'	129°54.3'	188	20	"	16 July - 23 Sept. 1977 (69 days)	"	"	"
"	CS2	52°55.0'	129°37.0'	205	23	"	4 July - 16 July 1977 (12 days)	"	"	"
"	CS2	"	"	205	15	"	16 July - 21 Sept. 1977 (67 days)	"	"	Temperature and pressure recorded
"	CS2	"	"	205	200	"	20 May - 16 July 1977 (57 days)	"	"	"
"	CS2	52°50.0'	129°37.0'	205	200	"	16 July - 23 Sept. 1977 (69 days)	"	"	Temperature, conductivity and pressure recorded
"	CS3	52°54.0'	129°19.0'	250	20	"	20 May - 16 July 1977 (57 days)	"		"

Area	Station Number	Lat.N.	Long.W	Depth (m)	Depth of Observations (m)	Sampling Interval	Period of Observations	Methods of Observations	References	Remarks
Caamano Sound	CS3	52°54.2'	129°19.4'	250	20	15 mins.	16 July - 21 Aug. 1977 (36 days)	Aanderaa current meter	Huggett <u>et</u> <u>al</u>, 1980	Temperature, conductivity and pressure recorded
Otter Channel	OC1	53°11.9'	129°30.1'	275	15	"	20 May - 18 July 1977 (59 days)	"		Temperature and conductivity recorded
Douglas Channel	CM1	53°56.7'	128°41.3'	207	45,10,175	"	10 July - 27 Sept. 1977 (79 days)	"	Webster, 1979a; Webster & Ford, 1979.	These observations were made from moored buoys. Pertinent meteorological data are also available from 3 sites in the area.
"	CM2	53°30.8'	129°12.0'	371	30,165,305	"	9 July - 27 Sept. 1977 (80 days)	"	"	
"	"	"	"	"	"	"	27 Sept.-12 Dec. 1977 (76 days)	"	"	"
"	"	"	"	"	"	"	12 Dec. 1977 - 6 Mar. 1978 (85 days)	"	"	"
"	"	"	"	"	"	"	7 Mar. - 9 June 1978 (94 days)	"	"	"
"	CM3	52°30.1'	129°12.1'	375	5,15	"	11 July - 27 Sept. 1977 (78 days)	"	"	"
"	"	"	"	"	"	"	27 Sept.-12 Dec. 1977 (76 days)	"	"	"
"	"	"	"	"	"	"	12-30 Dec. 1977 (18 days)	"	"	"
Squally Channel	CM4	52°59.9'	129°14.9'	325	35,15,0, 265	"	8 July - 26 Sept. 1977 (80 days)	"	"	"
	"	"	"	"	"	"	26 Sept.-7 Dec. 1977 (72 days)	"	"	"

Area	Station Number	Lat.N.	Long.W	Depth (m)	Depth of Observations(m)	Sampling Interval	Period of Observations	Methods of Observations	References	Remarks
Verney Passage	CM10	53°32.5'	129°00.6'	26	5,20	1 minute	4 Oct. 1977	Aanderaa current meter	Webster, 1979a; Webster & Ford, 1979.	These observations were made from moored buoys. Pertinent meteorological data are also available from 3 sites in the area.
Verney Passage	CM5	53°24.6'	129°07.9'	283	30,135,245	15 mins.	28 Sept.-8 Dec. 1977 (72 days)	"		
Devastation Channel	CM6	53°45.0'	128°49.3'	335	45,160,280	15 mins.	28 Sept.-12 Dec. 1977 (76 days)	"		" "
Verney Passage	CM10	53°32.5'	129°00.6'	26	5,15,25	2 mins.	5-17 Dec. 1977 (12 days)	"		Observations were not made from moored bucys. They were made from a ship maintained "on station."
Devastation Channel	CM11	53°40.8'	128°49.8'	324	5,15,55	2 mins.	8-17 Dec. 1977 (9 days)	"		Moored buoy measurements.
Otter Passage	CM8	53°12.0'	129°31.8'	267	40,135,230	15 mins.	10 Dec. 1977 - 6 Mar. 1978 (88 days)	"		"
Squally Channel	CM9	53°08.8'	129°22.5'	505	20,220,420	15 mins.	13 Dec. 1977 - 6 Mar. 1978 (85 days)	"		"
Grenville Channel	CM12	53°24.7'	129°23.9'	307	25,155	15 mins.	7 Mar.-9 June 1978 (94 days)	"		"
Squally Channel	CM15	53°12.0'	129°07.4'	555	30,245,	15 mins.	8 Mar.-9 June 1978 (93 days)	"		"

TABLE 6

Wave measurements in Hecate Strait and vicinity.

Area	Station Number	Lat. (N)	Long. (W)	Depth (m)	Period Of Observations	References	Remarks
Prince Rupert	88	54°14.2'	130°20.3'	-	19 April - 23 July 1976 (96 days)	Marine Environmental Data Service. 1978.	
Prince Rupert	104	54°11.2'	130°30.1'	-	28 Sept/72-13 June/73 (259 days)	"	
Kincolith	113	54°59.8'	129°58.8'	-	10 March/77-27 Feb/78 (355 days)	"	
Kitimat	118	53°58.9'	128°39.2'	-	10 July/77-22 March/78 (256 days)	"	
Hecate Strait	B-10 (SOCKEYE)	52°49.1'	131°00.7'	27	1-6 June 1968 (6 days) 4-6 July 1968 (3 days) 8-9 July 1968 (2 days) 11-13 July 1968 (3 days)	Hafer, 1970	These data were collected from drilling rig SEDCO 135F
Hecate Strait	E-66 (SOCKEYE)	52°45.4'	130°55.3'	60	27 July- 2 Aug. 1968 (7 days)	"	
Hecate Strait	G-41 (AUCKLET)	52°20.3'	130°36.5'	169	20-24 Aug. 1968 (5 days)	"	
Hecate Strait	I-74 (SOUTH COHO)	53°33.5'	131°25.8'	22	19-30 March 1969 (12 days)	"	
Hecate Strait	L-15 (MURRELET)	52°24.7'	130°47.6'	115	10-18 April 1969 (9 days)	"	

TABLE 7

Time series temperature measurements in the upper 50m depth in Douglas Channel and vicinity. All measurements were made with Aanderaa thermistor chains. The instruments consist of strings of 11 thermistors at 5m intervals.

Area	Station Number	Lat. (N)	Long. (W)	Depth (m)	Depth of Observations	Sampling Interval	Period of Observations	References	Remarks
Kitimat Arm	TM1	$53^{\circ}57.0'$	$128^{\circ}41.2$	198	0-50m	2 minutes	10-15 July 1977 (6 days)	Webster and Ford, 1979; Webster 1979a.	
"	"	"	"	"	"	30 minutes	15 July - 27 Sept./77 (74 days)	"	
Kitimat Arm	"	"	"	"	"	2 minutes	28 Sept. - 3 Oct. 1977 (5 days)	"	
"	"	"	"	"	"	30 minutes	3 Oct. - 11 Dec., 1977 (69 days)	"	
"	"	"	"	"	"	30 minutes	9 March - 10 June 1978 (93 days)	"	
Douglas Channel	TM2	$53^{\circ}31.6'$	$129^{\circ}12.0'$	355	"	2 minutes	9-15 July 1977 (7 days)	"	
"	"	"	"	"	"	30 minutes	15 July-27 Sept. 1977 (74 days)	"	
"	"	"	"	.	"	2 minutes	28 Sept. - 3 Oct. 1977 (5 days)	"	
"	"	"	"	"	"	30 minutes	3 Oct.-12 Dec. 1977 (70 days)	"	
"	"	"	"	"	"	30 minutes	7 March-29 April 1978 (53 days)	"	
Campania Sound	TM3	$52^{\circ}58.7'$	$129^{\circ}15.0'$	269	"	2 minutes	8-14 July 1977 (7 days)	"	
"	"	"	"	"	"	30 minutes	14 July-26 Sept. 1977 (74 days)	"	
"	"	"	"	"	"	2 minutes	26 Sept.-3 Oct., 1977. (7 days)	"	

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ABSTRACT

An examination of sea level records at ports in British Columbia shows that the largest departures of predicted tides from observed sea levels are due to the weather. Storms and river flows which force sea level changes persist for several days to a year, and can be identified in sea level records from which the shorter period tides have been filtered out. In this report, the nature of these sea level changes is examined. For given wind and air pressure changes, sea level fluctuations can be computed, but predictions of these changes are no more accurate than weather forecasts. Annual changes are more regular and can be predicted. Fortnightly and monthly tides are also examined, and criteria for their inclusion in tidal predictions are presented.

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1. Introduction

In British Columbia waters, largest sea level fluctuations are at semi-diurnal (twice daily) and diurnal (daily) frequencies, and the combined effect of these tides drives one or two high and low waters every day. These tides, and the currents generated by them have been monitored and predicted in British Columbia waters since the early 1900's. Because the gravitational pull of the moon and sun generates the diurnal and semi-diurnal tides, and the orbits of the earth and moon are so regular, these tides can be predicted years into the future with great accuracy.

At periods longer than a day, sea level changes are smaller and less regular. There are tides at periods of two weeks, a month, six months and a year, of smaller amplitudes driven by the same gravitational forces, but sea level changes caused by meteorological forces often dominate over these tides. Most meteorological forces such as winds, summer heating and air pressure changes originate from solar radiation, and the sea level changes which they generate are called radiational tides to distinguish them from the more regular gravitational tides.

Winds and air pressure changes over the ocean force sea level fluctuations at shore and over the continental shelf; winds blowing parallel to the shoreline can drive currents along the coast. The currents and sea level changes track each other so closely along the west coast of Vancouver Island that currents at periods of two days to a year can be monitored from sea level changes at shore. For periods less than a year, these sea levels, being meteorologically forced, cannot be predicted with sufficient accuracy for inclusion in tide tables. However, annual winds and air pressures follow a regular pattern, forcing sea levels up about 20 cm in winter with adequate reliability to be included in sea level predictions.

Because semi-diurnal and diurnal tides dominate, I have included here a brief description of their nature and predictability. Longer period sea level changes are discussed in the following sections.

Typical tidal curves for eight British Columbia ports for February 1976 are shown in Figures 2 and 3. Their positions are plotted in Figure 1. Tidal range decreases from north to south, from a maximum of 6 metres at Queen Charlotte City to 2 metres at Victoria. Also, the nature of the tide changes at Victoria where the semi-diurnal components fade out, leaving only one high and low water a day for half of the month. To illustrate these changes, a co-tidal chart of M_2, the principal lunar semi-diurnal tide is found in Figure 4. Co-amplitude lines join points where the tide has the same amplitude; co-phase lines describe the wave direction, joining points of similar phase of the tide. The M_2 tidal wave moves at a right angle to the co-phase line, toward higher phase, so the deep water tide progresses counter-clockwise around the Gulf of Alaska, increasing in amplitude toward the northeast. The tide approaches the coast then with higher amplitudes in the northern part of the province.

The tide is further modified by resonance and friction near the coast. The semi-diurnals turn north near Victoria in a way to decrease in amplitude on the Canadian shore, increase on the American side, leaving Victoria with the small semi-diurnal tides shown in Figure 2. Because the tides are slowed as they propagate through Juan de Fuca Strait and Discovery Passage the phases are delayed in Georgia Strait, but within Georgia Strait travel times are small and the Vancouver tide shown in Figure 2 represents tides over most of the Strait.

Figures 2 and 3 show the predicted tide at the eight British Columbia ports, prepared from analysis of previous sea levels. These were compared with the observed tide in February 1976, to produce residual tides (observed minus predicted) displayed in Figures 5 and 6. If a residual tide is significant, it will produce the short period oscillations found in the Queen Charlotte City and Langara Island plots. Both gauges are located in difficult places. Langara is a remote gauge in an exposed location. The difficulties in maintenance of the gauge may permit clock errors which can shift the observed tide. Queen Charlotte City, which experiences the largest tides in British Columbia, is on a shallow shelf where frictional effects can be large and variable. The remaining ports show smaller residual tides, and at Tofino it is barely observed.

The second feature noted in the residual tides is that meteorological forcing, especially in February which these plots show, causes the largest residual sea level changes, and these fluctuations are often uniform along the British Columbia coast. For example, the large positive levels at days 39 and 48 are found at every station. At Vancouver, Victoria, Tofino and Prince Rupert they easily dominate the tidal residuals. An inverted barometer effect, that is, the adjustment of sea level to changes in air pressure, drives most of these fluctuations, while the wind is of secondary importance.

No fortnightly or annual tidal constituents were included in the tidal predictions at these eight ports. Over much of the month of February 1976 the residual tides were positive, indicating observed values were greater than predicted, due to higher waters normally observed in winter driven by the lower air pressures and northward winds at that time of year. An annual tidal constituent, Sa, computed in Section III could reduce this residual.

Section II describes fortnightly and monthly tides, driven by the moon, normally overpowered by meteorological forcing at these frequencies. The nature of this meteorological forcing is given in Section IV.

Figure 1. Chart of the British Columbia Coast.

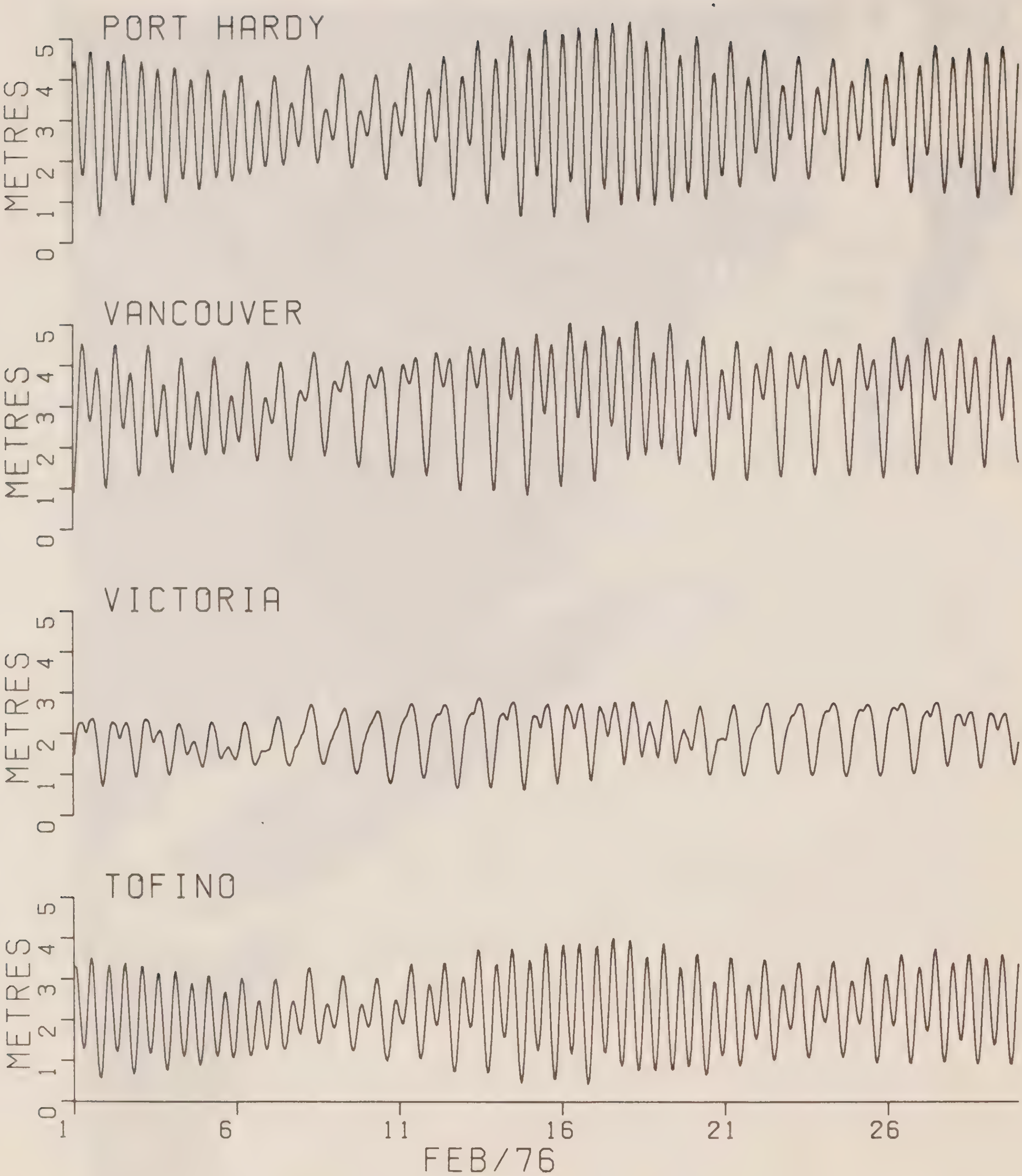
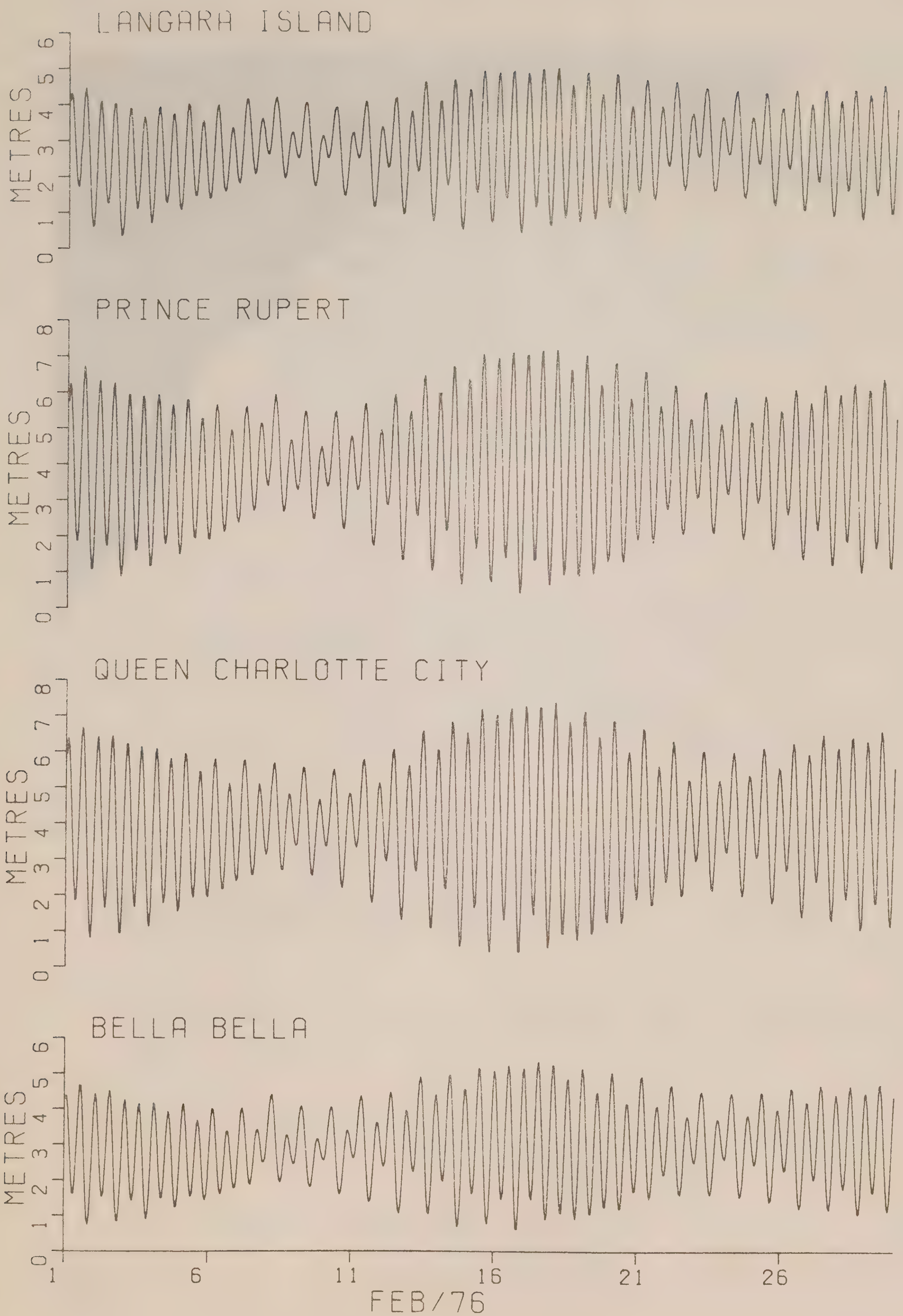


Figure 2. Predicted tides at ports surrounding Vancouver Island, February 1976.



gure 3. Predicted tides at ports in Northern British Columbia, February 1976.

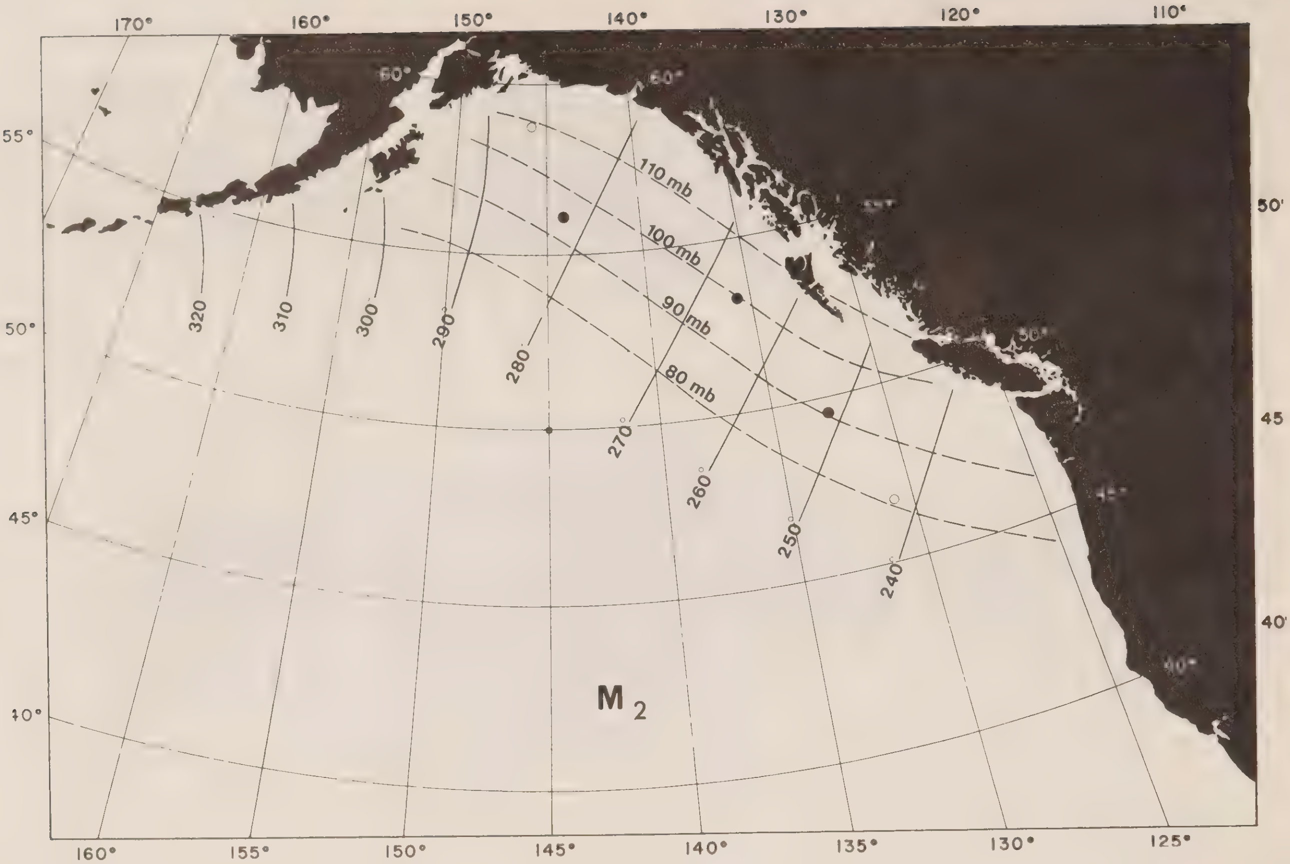


Figure 4. Co-tidal chart of M_2, the principal lunar semi-diurnal constituent. Solid circles are positions of Canadian gauges, open circles represent U.S. gauges. Positions of offshore gauges are, from south to north, Cobb, Union, Bowie and Surveyor Seamounts, and Middleton Is. Figure from Crawford, Rapatz and Huggett, 1980.

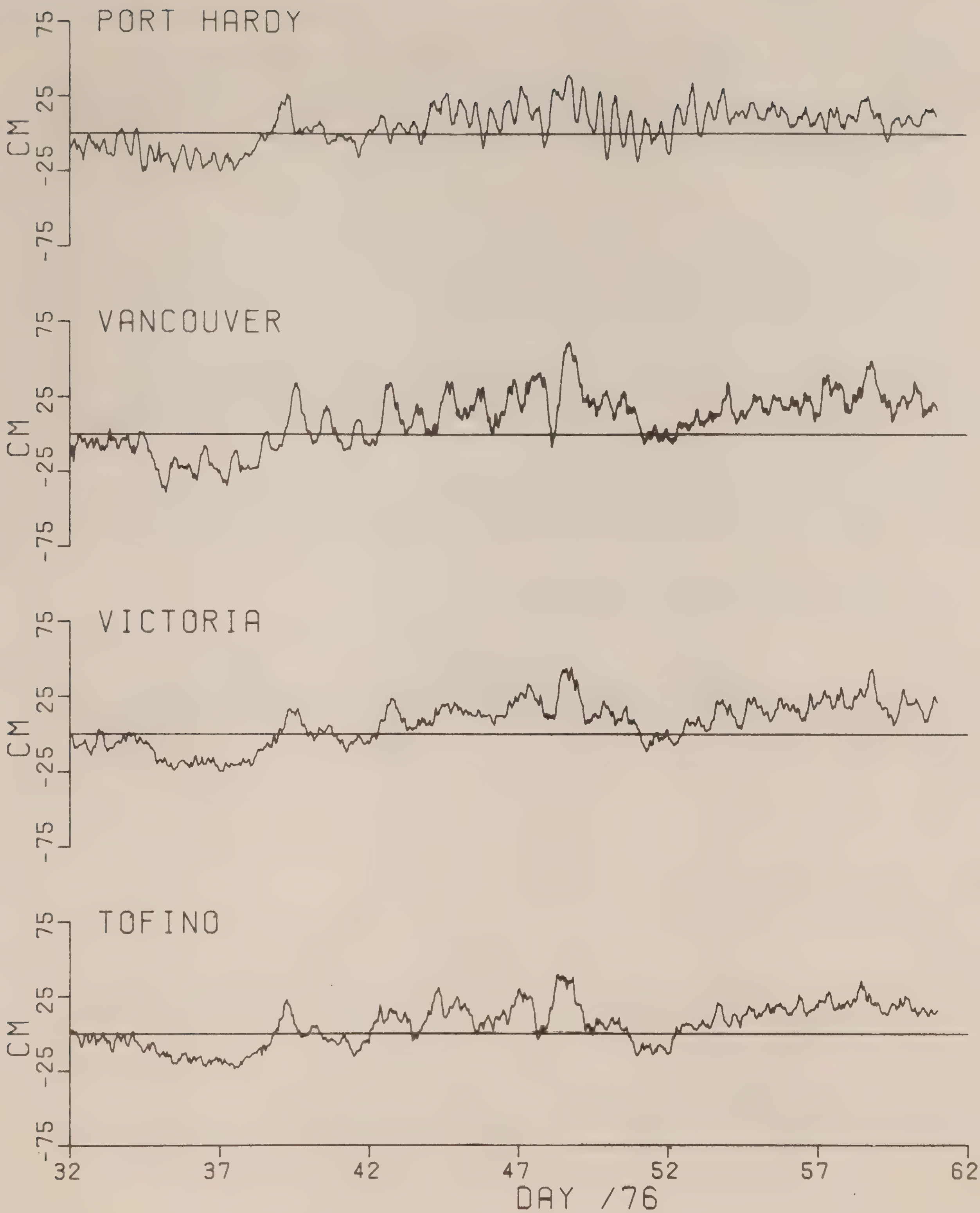


Figure 5. Residual sea levels at ports surrounding Vancouver Island, February 1976.

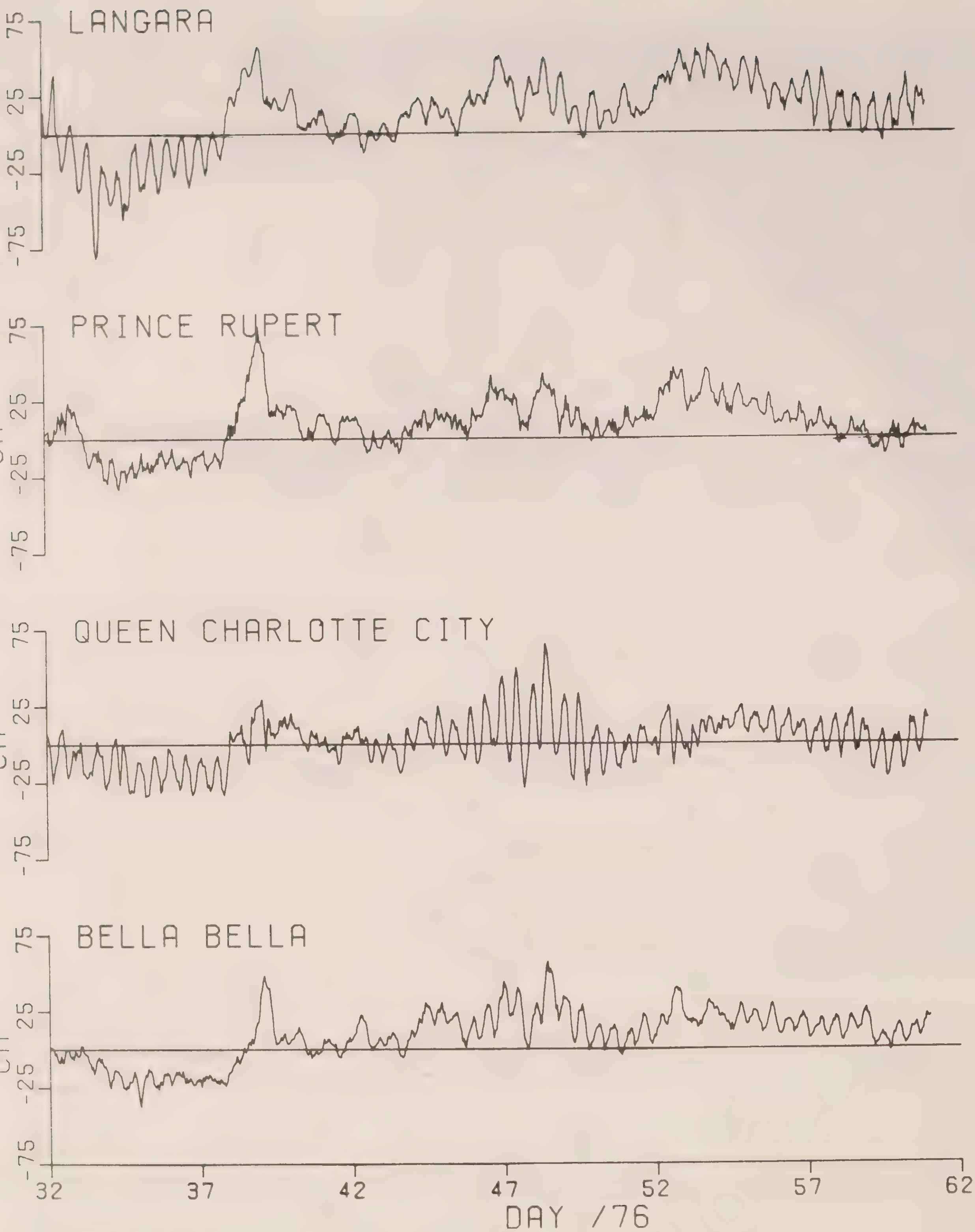


Figure 6. Residual sea levels at ports in Northern British Columbia.

II. Fortnightly and Monthly Tides

There are weak tidal influences at periods of two weeks and one month which have an effect upon sea level, but this effect is usually obscured by meteorological forcing; to resolve and predict these tidal constituents several years of data are required. The results of a statistical study of 14 to 19 years of data at Victoria, Vancouver, Tofino and Prince Rupert to determine these tidal constituents are presented in this section.

Recent studies of water levels and currents along the west coast of the United States (Huyer, Smith and Sobey, 1978) have shown that at periods longer than several days, both are strongly influenced by the winds. To compare these signals, one treats the fortnightly and monthly tides as noise, to be carefully removed from the data, before proceeding with examination of the effect of winds upon currents and tidal heights. The amplitudes and phases of these tidal constituents are required then for accurate prediction of water levels, and to allow separation of wind and tidal influences upon sea levels.

When water level records are analyzed with harmonic analysis schemes to extract tidal constituents, there are several constituents of periods near two weeks and one month which are often included. The four largest are listed in Table I.

Table I. Fortnightly and Monthly Tidal Constituents

Constituent	Frequency (cycles/day)	Period (days)	Equilibrium[1] Potential	shallow water tide
Msm	0.03143	31.81	-.00673	λ_2-M_2
Mm	0.03629	27.55	-.03517	N_2-M_2
Msf	0.06773	14.77	-.00583	S_2-M_2
Mf	0.07320	13.66	-.06669	K_2-M_2,K_1-O_1

([1] ref - Cartwright and Edden, 1973)

The equilibrium potential is proportional to the height of the tide in an ocean which is always in equilibrium with the tidal forcing function. However, the tide at any one port depends strongly upon the response of the adjacent sea, which limits the usefulness of the equilibrium potential to comparisons between constituents of similar frequencies. In Table I, the equilibrium potential was the basis of elimination of smaller long period constituents not listed. The equilibrium potential of M_2, the largest constituent, is 0.63, a factor of ten larger than Mf, the strongest long period tide.

The equilibrium potential gives the strength of the astronomical forcing, but all four tidal lines are also at frequencies which are the difference between two semi-diurnal tides. If turbulent friction affects the tide at a port or in a basin adjacent to a port, the purely linear response of

the tide will be lost, and tidal variations in sea level will be found at frequencies which are the sum and difference of the larger constituents. Because turbulent friction is strongest where the water is shallow, these variations in sea level are called shallow water tides. The pairs of semi-diurnal tides whose difference in frequency gives a long period shallow water tide are listed in Table I. The order of these tides for British Columbia ports in decreasing strength is M_2, S_2, N_2, K_2, so the strongest interaction will be found in the constituent Msf which is at the difference in frequency between S_2 and M_2, the principal solar and lunar semi-diurnal tides.

As noted earlier, most of the changes in sea levels at ports in British Columbia at periods of two weeks and a month are due to meteorological forcing. For example, the ocean responds to sea surface pressure changes in a way to minimize the changes in pressure at the ocean bottom; a drop in air pressure of one millibar (100 pascals) will force a sea level rise of approximately one centimeter, (the inverted barometer effect). The geostrophic adjustment of the oceanic flow can cause sea level to undershoot the inverted barometric response (Crepon, 1976), but observations of bottom pressures in the ocean (Brown et al, 1975, Crawford, Rapatz and Huggett, 1980) have found that the ocean, away from continental shelves, behaves largely as an inverted barometer. However, there is a tendency on the continental shelf of the western North American coast for an inverted barometric overshoot, due, as mentioned before, to the effect of the wind, and to shelf waves generated by the wind.

A standard procedure for analysis of ocean tides is to run a harmonic analysis program on one year of an hourly height time series of sea levels. Harmonic analysis is a least squares fit of cosine functions with periods equal to the main equilibrium tidal periods, and to the appropriate sum and difference frequencies for the shallow water tides. A recent scheme, written by Foreman (1977) has 45 astronomical constituents and 24 shallow water constituents, with options for up to 77 additional shallow water constituents. The optimal length of record is one year; the analysis can be improved by running separate analyses on successive years of data.

Results of 19 one year analyses at Victoria and 14 at each of Prince Rupert, Tofino and Vancouver are shown in Tables IIa to IId. The variations from year to year in the long period tides are very large in both amplitude and phase. Vector averages and standard deviations are computed according to the following formulae. If the amplitude is A_j and the phase is Θ_j, then

$$\overline{A}_x = \frac{1}{N} \Sigma_{j=1}^{N} A_j \cos\Theta_j$$

$$\overline{A}_y = \frac{1}{N} \Sigma_{j=1}^{N} A_j \sin\Theta_j$$

$$\overline{A} = (\overline{A}_x{}^2 + \overline{A}_y{}^2)^{1/2}$$

$$S = \left[\frac{\sum_{j=1}^{N}(A_j\cos\Theta_j - \overline{A}_x)^2 + \sum_{j=1}^{N}(A_j\sin\Theta_j - \overline{A}_y)^2}{N-1} \right]^{1/2}$$

Table IIa. Amplitude in millimetres and phase in degrees of four main fortnightly and monthly tides at Tofino, British Columbia (49°09'N, 125°55'W) computed by harmonic analysis.

TOFINO

	Mf		Msf		Mm		Msm	
Year	Amp	Phase	Amp	Phase	Amp	Phase	Amp	Phase
1963	32	181	29	175	8	208	30	203
1964	25	257	25	158	27	89	24	219
1965	22	204	10	181	52	202	17	160
1966	34	208	14	165	4	130	34	349
1967	29	204	23	83	18	279	50	29
1968	18	169	16	145	26	222	4	37
1969	38	158	26	107	58	121	17	150
1971	20	228	17	42	35	204	28	265
1972	20	138	29	253	20	303	25	327
1973	19	170	30	234	25	38	26	154
1974	34	121	53	174	23	138	25	181
1975	9	126	45	192	32	137	20	180
1976	15	137	27	234	2	75	8	227
Vector average amplitude and phase	18.8	174	15.8	187	10.2	164	4.6	208
Standard deviation	17.9		25.2		28.0		25.8	

Table IIb. Amplitude in millimetres and phase in degrees of four main fortnightly and monthly tides at Victoria, British Columbia (48°25'N, 123°22'W) computed by harmonic analysis.

VICTORIA

	Mf		Msf		Mm		Msm	
Year	Amp	Phase	Amp	Phase	Amp	Phase	Amp	Phase
1958	17	22	8	162	18	292	6	264
1959	25	216	14	91	29	171	5	351
1960	13	136	7	321	8	137	18	26
1961	12	123	11	253	10	168	44	292
1962	18	348	6	0	8	23	10	255
1963	27	174	23	168	3	192	32	211
1964	21	287	27	153	22	108	21	201
1965	12	181	3	158	50	193	15	185
1966	23	199	20	161	3	192	40	348
1967	18	205	17	79	19	254	41	25
1968	8	143	12	150	20	230	8	311
1969	20	111	28	289	21	307	4	81
1970	24	167	25	96	46	122	15	136
1971	3	292	10	48	36	201	30	285
1972	16	112	28	271	19	311	18	333
1973	24	181	31	245	24	33	13	157
1974	27	118	41	184	19	161	20	157
1975	11	70	35	196	34	127	18	207
1976	10	136	19	249	5	332	3	115
Vector average amplitude and phase	8.7	160	8.3	192	8.3	176	4.7	283
Standard deviation	16.9		20.7		23.8		22.9	

Table IIc. Amplitude in millimetres and phase in degrees of four main fortnightly and monthly tides at Vancouver, British Columbia ($49^{\circ}17'$N, $123^{\circ}07'$W) computed by harmonic analysis.

VANCOUVER

	Mf		Msf		Mm		Msm	
Year	Amp	Phase	Amp	Phase	Amp	Phase	Amp	Phase
1963	27	162	20	192	4	261	44	211
1964	14	302	24	131	26	100	18	218
1965	22	144	12	313	44	212	12	175
1966	17	204	27	171	11	10	46	340
1967	18	151	19	64	19	292	44	24
1968	19	110	10	120	12	240	14	322
1969	32	103	32	298	29	323	4	79
1970	28	139	37	87	47	112	15	133
1971	10	66	16	66	27	205	33	286
1972	25	88	20	295	23	346	23	330
1973	20	140	15	264	42	35	10	153
1974	34	111	39	178	17	132	21	175
1975	23	69	31	195	30	107	17	205
1976	22	119	14	261	17	14	12	82
Vector average amplitude and phase	16.8	123	6.5	178	3.7	87	4.1	278
Standard deviation	16.4		24.2		28.6		26.5	

Table IId. Amplitude in millimetres and phase in degrees of four main fortnightly and monthly tides at Prince Rupert, British Columbia ($54^{o}19'N$, $130^{o}20'W$) computed by harmonic analysis.

PRINCE RUPERT

	Mf		Msf		Mm		Msm	
Year	Amp	Phase	Amp	Phase	Amp	Phase	Amp	Phase
1963	40	183	18	197	23	15	28	211
1964	20	232	18	33	44	167	9	136
1965	34	192	34	281	51	185	17	63
1966	21	203	13	107	11	192	36	336
1967	20	223	28	89	11	4	40	6
1968	28	175	9	109	30	223	6	142
1969	25	151	30	294	27	267	9	218
1970	38	162	38	21	54	116	10	190
1971	20	191	13	21	22	211	19	286
1972	14	147	19	323	25	314	37	33
1973	29	160	24	280	51	69	12	275
1974	26	116	19	138	32	118	41	169
1975	6	65	22	199	5	125	20	261
1976	34	132	9	210	32	47	11	107
Vector average amplitude and phase	21.4	171	3.2	328	9.2	138	1.9	316
Standard deviation	17.0		23.4		33.2		25.1	

$$\theta = \mathrm{Tan}^{-1}\ (\overline{A}_y/\overline{A}_x)$$

where N is 19 for Victoria, 14 for the remaining ports.

Only for the Mf constituent at several ports is the standard deviation of the amplitude less than the amplitude itself, and for Mf the two are of similar magnitude. These results show that Mm, Mf, Msm, Msf should not be included in the harmonic analysis of one year tidal records.

One hopes to employ an analysis scheme which shows the relative contributions of tides and weather to sea level records. This is most easily done with a Fourier analysis covering the entire data record at once. The weather which contaminates the tides has a continuous spectrum, while the tidal signals have line spectra. By choosing longer time series, the noise continuum is spread over more Fourier coefficients, and the amplitude of the tidal lines does not diminish. In theory then, any tidal constituent can be resolved by choosing a record sufficiently long.

Wunsch (1967) examined sea level records from islands in the central Pacific to the south of Hawaii, as well as from Hawaii and California. He found amplitudes for Mf to be usually in the range of 0.5 to 1.0 cm, with significant departures of the phases from that of the equilibrium tide. A record four years long was required for the fortnightly tide to rise significantly above the background noise at a tidal station in the tropics. At our higher latitudes where the meteorological conditions are generally more variable and the meteorologically forced portion of the background noise is greater in amplitude, longer records may be required.

The equilibrium tide Mf is given by Lisitzin (1974) as

$$W = V(1\text{-}3\ \sin^2 \phi)\ \cos 2s$$

where s is the period of revolution of the moon, ϕ is latitude and V is the potential. When allowance is made for the elastic deformation of the earth, the equilibrium amplitude of Mf becomes

$$\Delta H = 13.9\ (1\text{-}3\ \sin^2 \phi)\ \cos 2s \text{ millimetres.}$$

$$= -9.9\quad \cos 2s \text{ millimetres at } 49^{\circ}\text{N (Tofino, Victoria, Vancouver)}$$

$$= -13.6\quad \cos 2s \text{ millimetres at } 54.3^{\circ}\text{N (Prince Rupert)}$$

If the actual tide shows a behavior similar to the equilibrium tide, we can expect larger amplitudes than Wunsch found in the tropics, and a slightly larger amplitude at Prince Rupert than Tofino. The change in sign of the amplitude near 32°N, where $(1\text{-}3\ \sin^2 \phi)$ changes sign introduces a change in phase of 180°. In the convention of harmonic analysis, the phase of a measured tide is compared with the phase of the equilibrium tide at the equator; a tide north of 32°N (or south of 32°S) will then be in equilibrium with the local potential when its phase is 180°. This convention is retained here.

The time series of hourly heights at Victoria, Vancouver, Tofino and Prince Rupert were low passed with an $A_{24}A_{25}A_{26}$ filter (Godin 1972) to remove the diurnal and semi-diurnal tides. The record at Tofino was free of gaps, and this low passed record sufficed to fill gaps in the low passed records at other stations (57 days at Victoria, 108 days at Vancouver, 16 at Prince Rupert). Data points at 12 hour intervals were chosen from the low passed records, and series of 9918 points (13.58 years) were selected, starting at 0100 PST January 4, 1963. Mf and Mm dominate the fortnightly and monthly tides, and 13.58 years comprise 363.01 cycles of Mf and 179.97 of Mm. Fast Fourier transforms of the series were computed, and the amplitudes of the first 500 coefficients are plotted in Figures 7b to 10b.

Records of hourly sea surface air pressures supplied by the Atmospheric Environment Service for Vancouver, Tofino and Prince Rupert airports were similarly analyzed. No gaps existed in these records. The record at Vancouver Airport served to compare with both Victoria and Vancouver tidal records. Fast Fourier transforms of 9918 points of the air pressure records, for the same time period beginning at 0100 PST, Jan. 4, 1963, were computed; the amplitudes are plotted in Figures 7a to 10a.

The units of the sea level records are millimetres, while the air pressure units are tenths of millibars, the two units being equivalent to within 1% for seawater. The amplitudes of sea level fluctuations predominate over the air pressures, particularly at the annual period. The 363rd Fourier coefficient, which lies closest in frequency to the Mf period clearly stands out from the neighboring values, but the 180th coefficient (Mm) does not.

For each port, the spectra of sea level and air pressure are similar; in fact it is possible to match many spectral peaks on a one-to-one basis. For an inverted barometer response, the phase shift is 180°, while for these four ports the shift is close to 180°, but differs in a significant fashion as shown later. At periods near one year (Fourier coefficients 14, 15) the sea level amplitudes are much greater than the air pressure amplitudes, and the semi-annual and ter-annual sea level amplitudes are also significant. Currents flowing along the west coast of Canada and the United States, generally northward in winter and weakly southward in summer, in geostrophic balance, set up sea level gradients which amplify the tendency of low sea levels in summer, high in winter due to direct atmospheric forcing. Further studies of seasonal sea level changes have been presented by Reid and Mantyla (1976) and results for British Columbia are presented in Section III.

At higher frequencies, the seasonal currents do not change sea levels at shore as much as narrower currents confined to the continental shelf and slope; these currents and the sea level changes which they generate can propagate from south to north as shelf waves. Theoretical studies (Adams and Buchwald 1969, Gill and Schumann 1974) have shown that such waves are generated by the alongshore component of the wind. Some of the most extensive studies of shelf waves were conducted in the early 1970's off the coast of Oregon, as part of the CUEA program to examine upwelling. These studies showed that adjusted sea levels at the shore (sea level plus atmospheric pressure in units of centimetres and millibars respectively) are closely related to alongshore currents and alongshore winds. Moreover the currents are strongly barotropic (Smith 1974, Huyer, Smith and Sobey 1978).

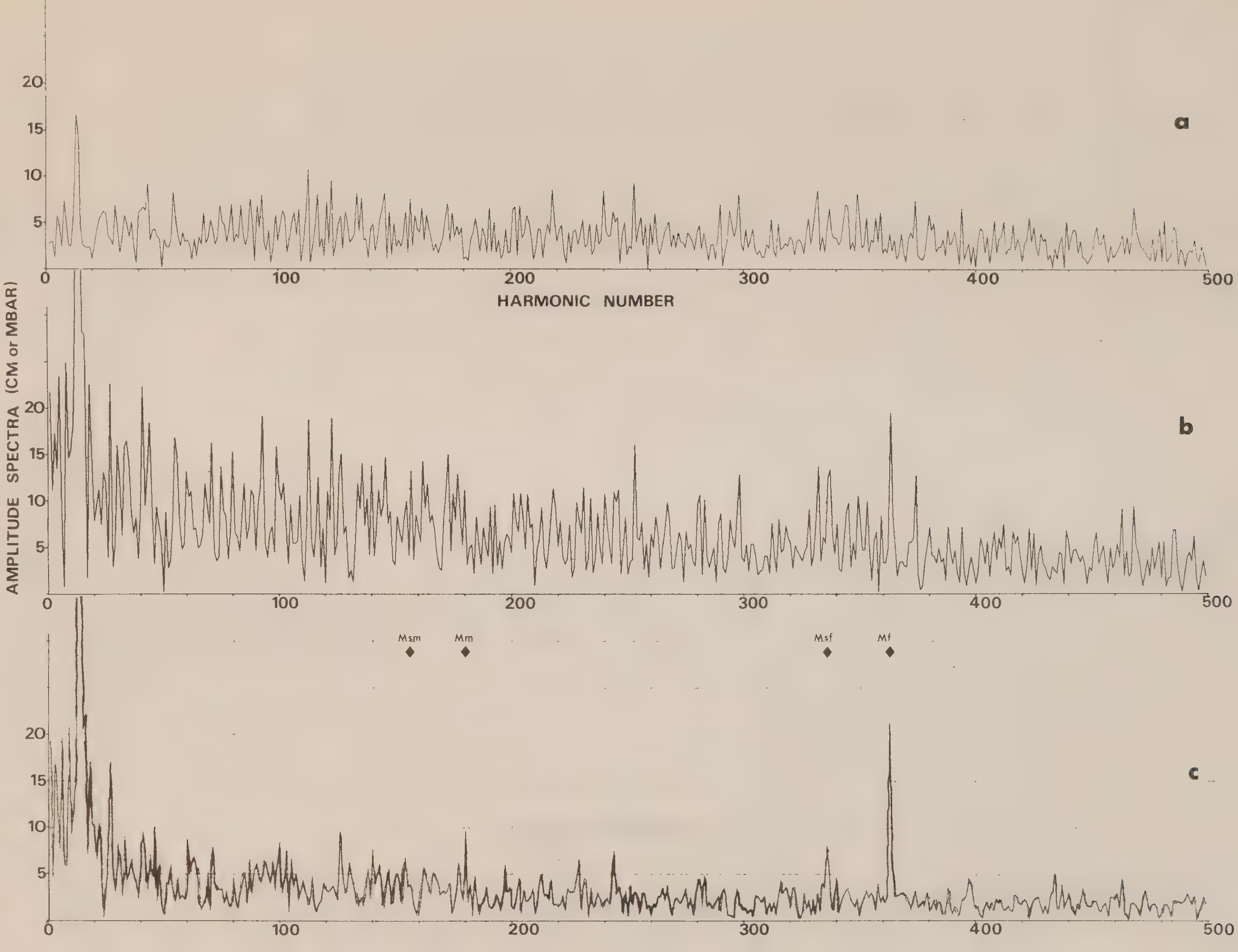


Figure 7. Amplitude periodograms of (a) air pressure, (b) sea level and (c) spectrally adjusted sea level at Tofino.

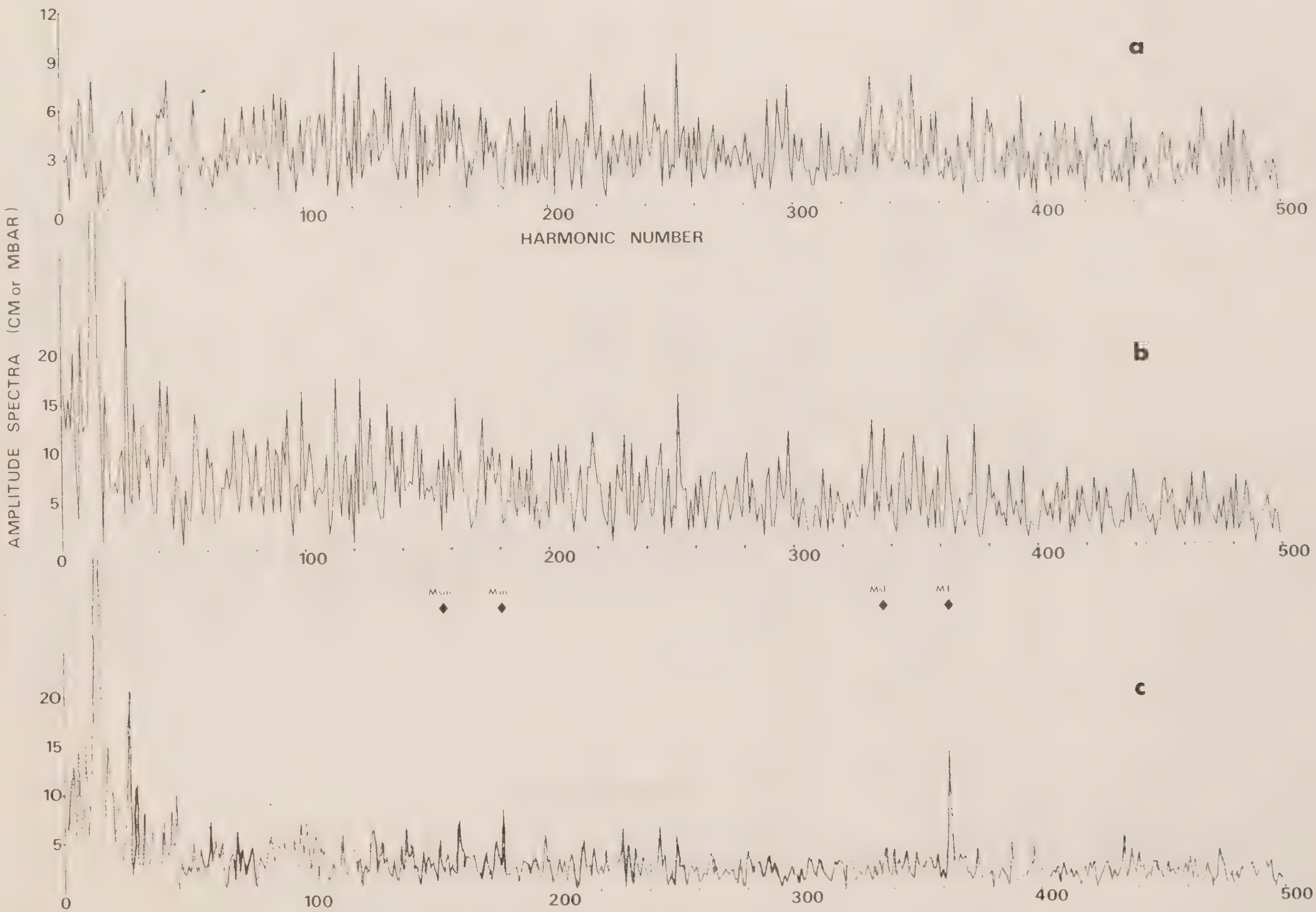


Figure 8. Amplitude periodograms of (a) air pressure, (b) sea level and (c) spectrally adjusted sea level at Victoria.

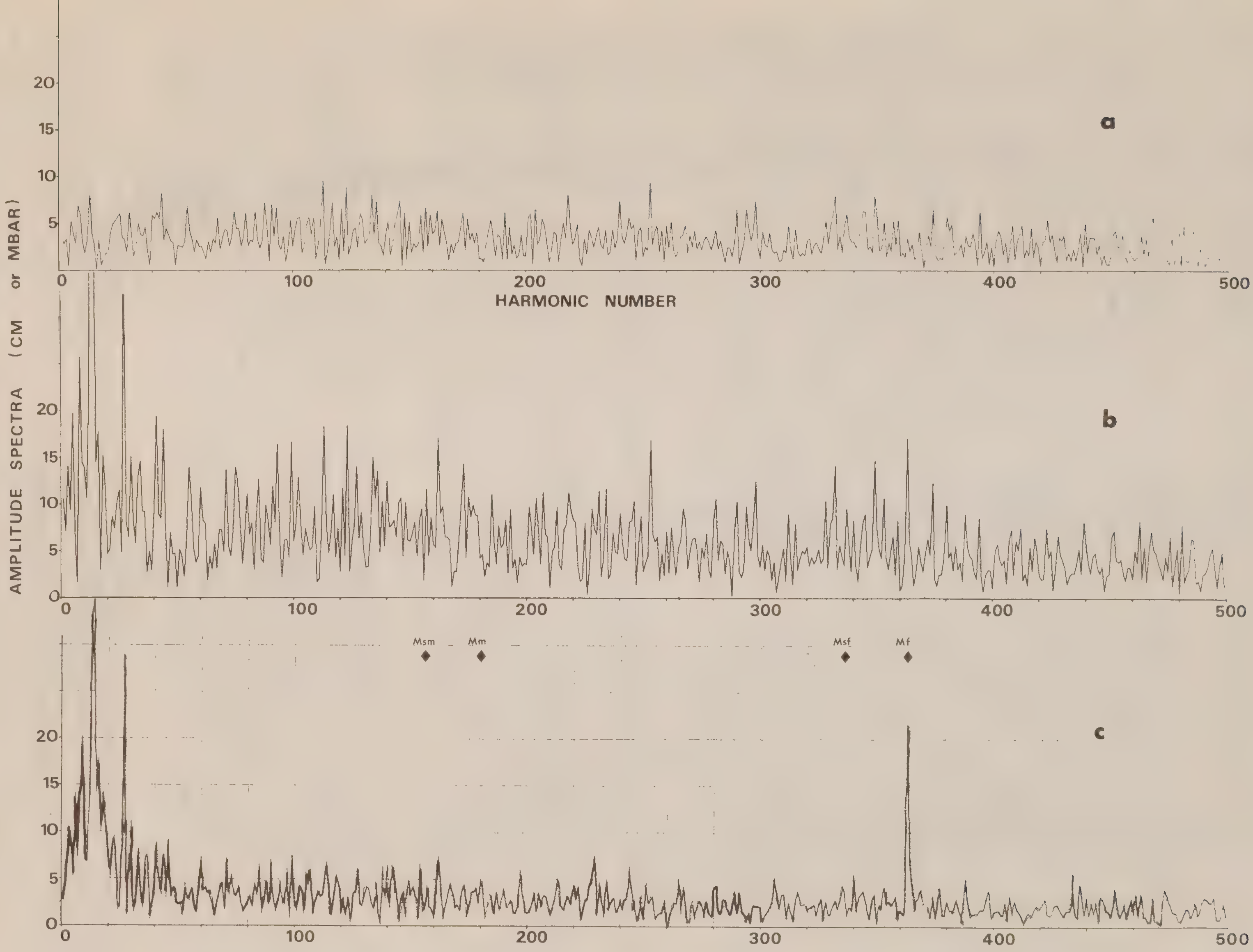


Figure 9: Amplitude periodograms of (a) air pressure, (b) sea level and (c) spectrally adjusted sea level at Vancouver.

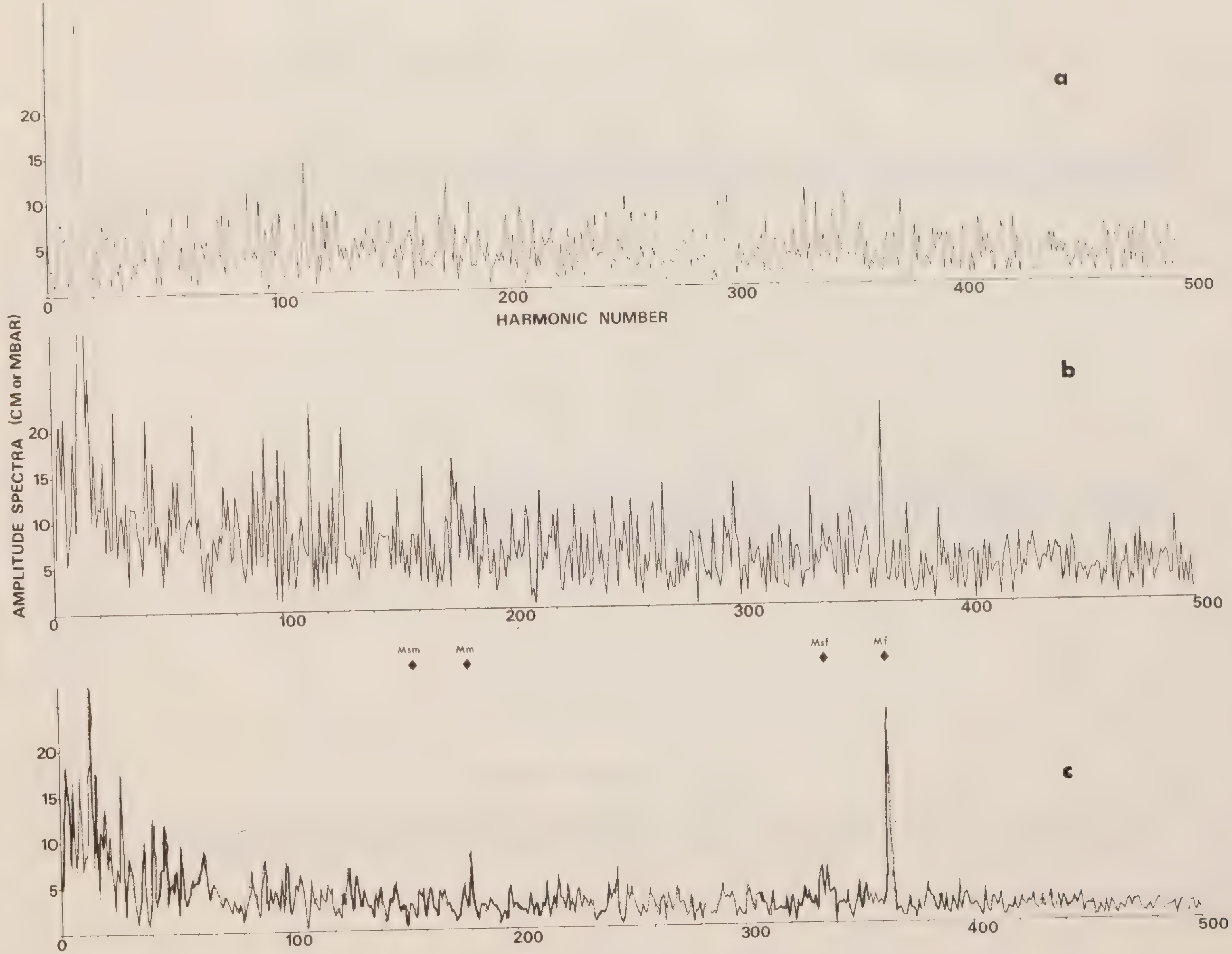


Figure 10. Amplitude periodograms of (a) air pressure, (b) sea level and (c) spectrally adjusted sea level at Prince Rupert.

A study by Osmer and Huyer (1978) shows that although a relationship between alongshore winds and adjusted sea levels is found along the coast between Tofino and San Francisco, the lowest correlation is found at Tofino, where the reported winds are not representative of the winds over the shelf waters.

We are left then, with the understanding that the tides, air pressure and winds all influence sea levels in British Columbia at periods of several days to a month. To isolate the effect of fortnightly and monthly tides, we need to know both the values of air pressure and wind, and their effect upon sea levels; however, only air pressure data are reliable. A first approximation is the inverted barometer relationship between air pressures and sea levels - i.e. the 'adjusted' sea level. Figures 7 to 10, parts a and b, show that much of the sea level change can be accounted for in this fashion. There is a tendency along the coast for an inverted barometer overshoot, which can be seen in Figures 7 to 10. The individual peaks in the sea level and air pressure periodograms correspond on a one-to-one basis, but are larger for sea levels. Overshoots (or undershoots, the opposite case) exist along many coastlines with continental shelves, such as the west coast of Australia (overshoot) and the east coast of North America and the east coast of Australia (undershoot). Where there is a tendency for alongshore winds and air pressures to act together to change sea levels in the same direction, an inverted barometer overshoot occurs. We can use this relationship to partially compensate for the effect of winds, through Fourier analysis.

Fourier Analysis to Remove the Meteorological Signal from Sea Level Records

It is possible to determine the coherence and admittance between two time series. The coherence is a measure of the amount of association between two time series over a band of frequencies, while the admittance is the phase difference and ratio of amplitudes of the coherent portion of the two time series. In the case of sea level and air pressure, an inverted barometer response would give a coherence of 1.0, admittance amplitude of 1.0 and phase of 180°. Coherence is normally denoted by γ.

To analyze the sea level and air pressure time series, the mean and any linear trend present in each of 8192 data points, beginning 0100 PST 4 January 1963, were removed. A one-tenth cosine bell filter was run over each time series. The values of admittance and phase, plotted in figures 11 to 14, were each computed over bands of 64 neighboring frequencies, and are plotted up to the frequency where the squared coherence falls below 0.5. At the frequencies near the Mm and Mf tides, values of γ^2 were between 0.74 and 0.90. The dashed lines in Figures 11 to 14 show the spectral form fitted to the admittance.

Tofino, Vancouver and Victoria display similar behavior, with phase shifts and admittance amplitudes decreasing as frequencies increase, until minima for both are reached at periods near 5 days for amplitude and 2.5 days for phase, after which both increase again. At Prince Rupert, the rise in admittance amplitude at higher frequencies is less steep, and the phase remains steady. Tofino, Vancouver and Victoria are closely spaced ports, and these results show that all three respond in the same fashion to the weather, while Prince Rupert is in a different regime. The inverted barometer overshoot

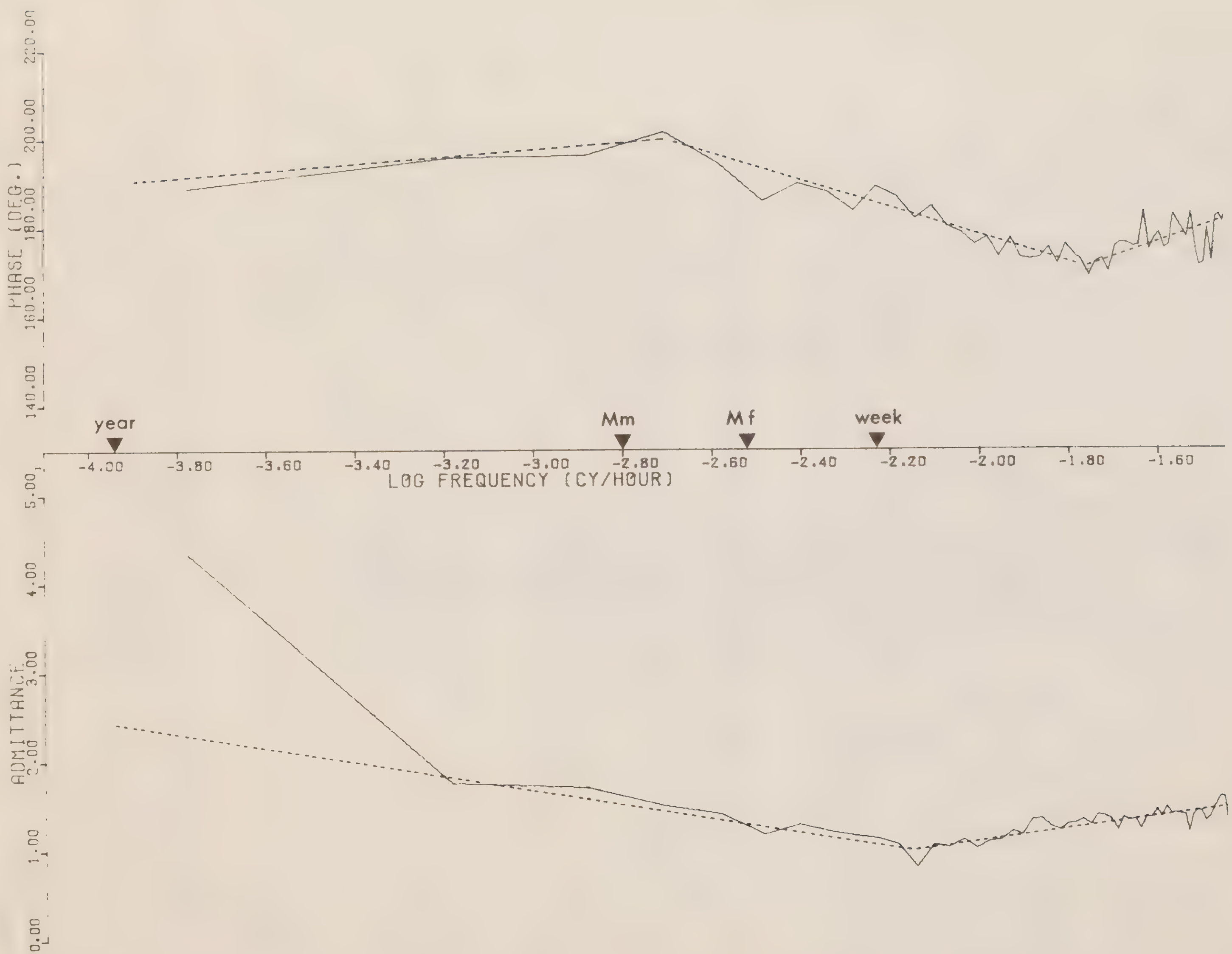


Figure 11. Admittance and phase relation between air pressure and sea level at Tofino.

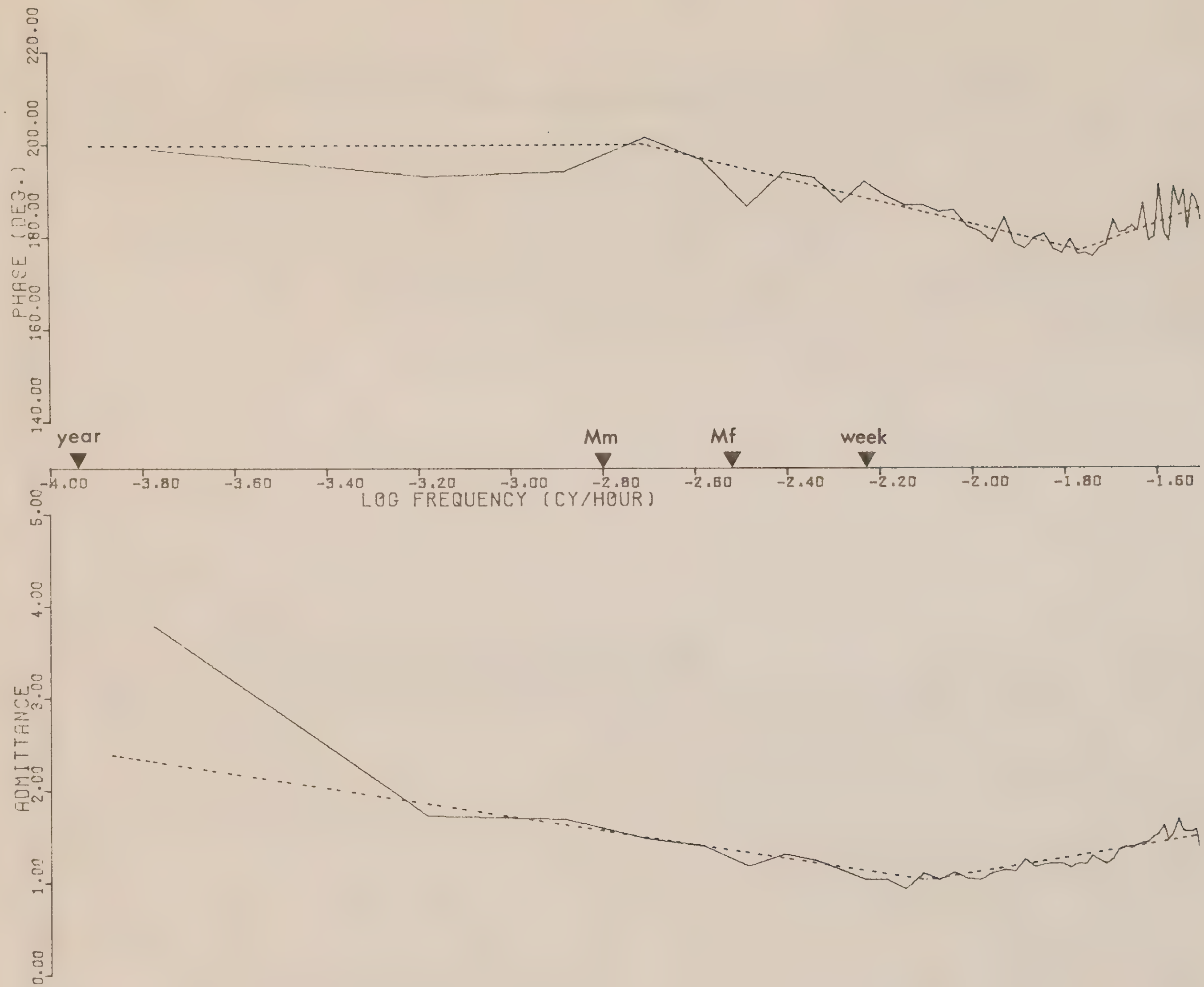


Figure 12. Admittance and phase relation between air pressure and sea level at Victoria.

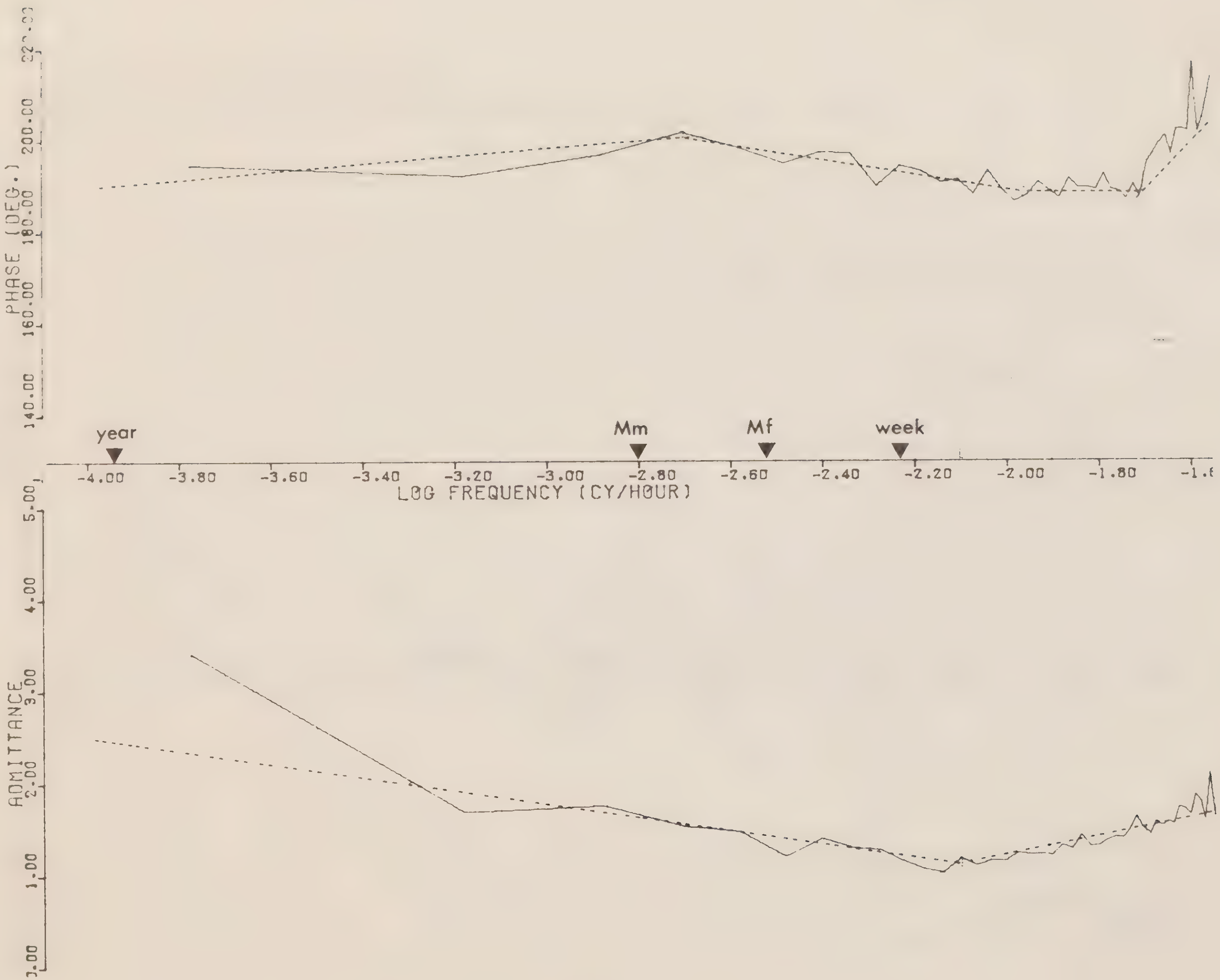


Figure 13. Admittance and phase relation between air pressure and sea level at Vancouver.

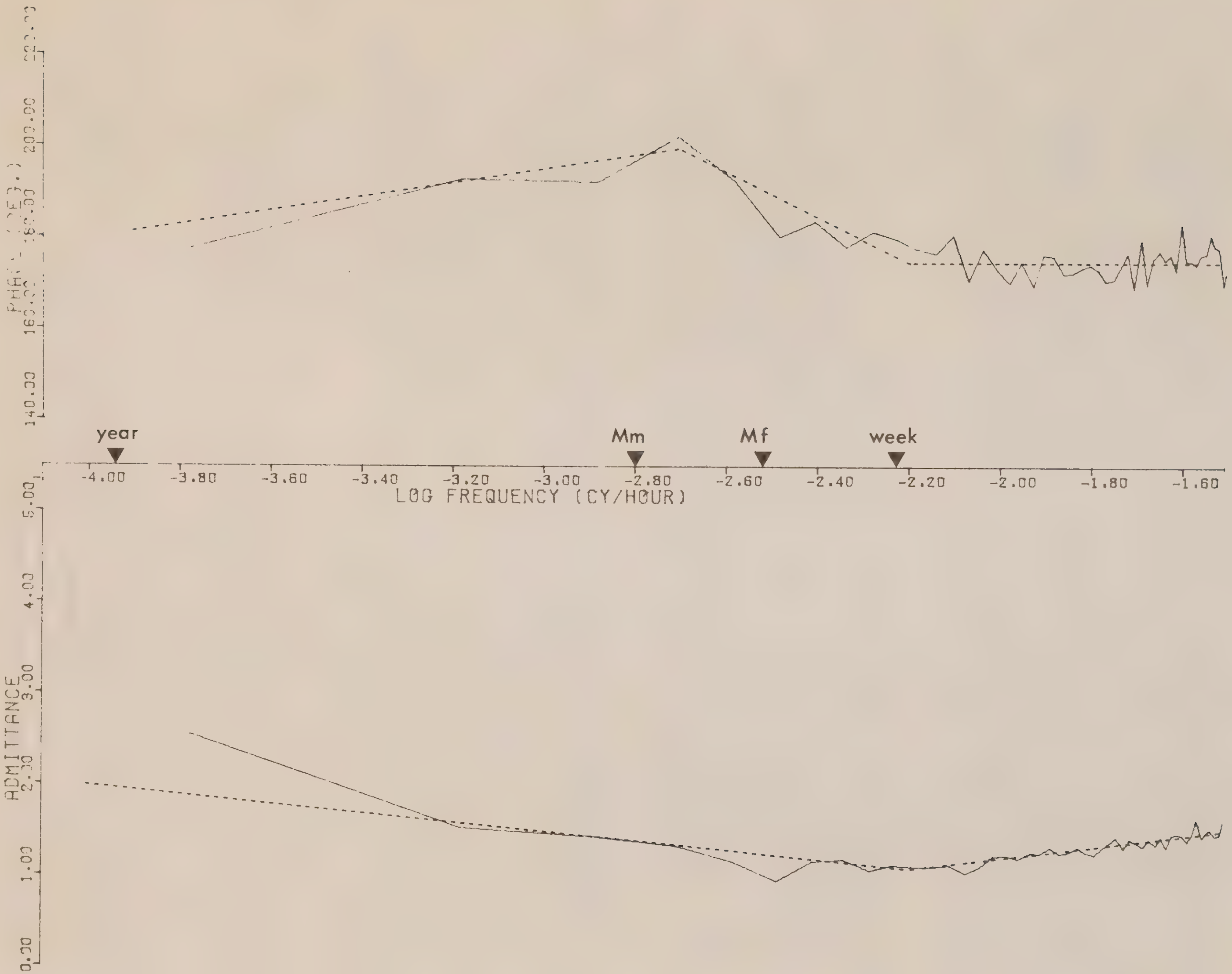


Figure 14. Admittance and phase relation between air pressure and sea level at Prince Rupert.

is evident at all four ports. Until accurate current and wind measurements are available, and the dynamics of shelf currents are understood, the cause of the phase and amplitude shifts will not be known.

The Mf tide in the sea level records has sufficient energy to shift the admittance for the entire spectral band centred at 12.8 days (Log frequency -2.489) and this band could not be used to form the spectral corrections for sea level data. The Mm tide with lower amplitudes does not appreciably influence the admittance.

The dashed line in Figures 11 to 14 was assumed to be the spectral relationship between sea level and air pressure, to remove the effect of air pressure from the sea level records. For example, the vector representing the amplitude and phase of Victoria air pressures at the Mm frequency was rotated 200°, multiplied by 1.57 (the values of phase and amplitude of the admittance shown in figure 12) and subtracted from the vector of sea level fluctuations at Victoria at the Mm frequency. Similar adjustments to the periodogram of sea levels at all four ports at all frequencies were made. Resulting adjusted sea level periodograms are plotted in Figures 7c to 10c. Tidal lines now rise clearly above the background noise. It remains to compute the amplitude and phase of these tides.

Computation of Amplitude and Phase of Long Period Tides

Although these tides appear in the amplitude spectra as single lines, they are more precisely a cluster of tidal lines as shown in Table III, but only the principal coefficients within each group have sufficient amplitude to penetrate the background noise. To compute the amplitude and phase of each tidal line, a time series was generated of the equilibrium tide of all the Msm, Mm, Msf and Mf groups listed in Table III for the period Jan. 4/63 to July 24/76, and this series was subjected to the same Fourier analysis.

Although the principal tides of Mf and Mm (Mf_4 and Mm_4) are very close to pure harmonics of the 14.58 year time series, the neighbouring tidal lines are not. They differ in frequency from the principals by multiples of one cycle in 18.61 years and/or one cycle in 8.85 years, the periods of rotation of the lunar node and lunar perigee respectively. The number of cycles difference is given by the fourth and fifth Doodson numbers in Table III. Because these neighbouring lines are not exact harmonics of the data record, when a Fourier transform is conducted, some of their energy will "leak" into the main constituent, and either augment or diminish its amplitude, depending upon the relative phases of the two.

If it is assumed that the response of the ocean to the equilibrium tidal forcing is uniform across the cluster of tidal lines forming each of the groups, then the Fourier transform values of the equilibrium tide will accurately represent the total relative tidal contribution at each Fourier frequency.

Consider the Mf group. The principal line has equilibrium amplitude 0.06663, and the amplitude of F.C.(363) of the equilibrium tide is 0.07466. The amplitude of F.C.(363) of the observed tide must be reduced by the ratio 0.06663/0.07466 to produce the amplitude of the Mf_4 constituent alone. Most of the modulation of Mf_4 is by Mf_5, a tidal line

Table III. Expansion of Msm, Mm, Msf, Mf Tidal Constituents

Constituent	Doodson Number	Equilibrium Potential
Msm_1	0 1 -2 -1 -2 0	0.00002
Msm_2	0 1 -2 -1 -1 0	0.00007
Msm_3	0 1 -2 1 -1 0	0.00048
Msm_4	0 1 -2 1 0 0	-0.00673
Msm_5	0 1 -2 1 1 0	0.00044
Mm_1	0 1 0 -1 -2 0	0.00003
Mm_2	0 1 0 -1 -1 0	0.00231
Mm_3	0 1 0 -1 0 0	-0.03518
Mm_4	0 1 0 -1 1 0	0.00229
Mm_5	0 1 0 1 0 0	0.00188
Mm_6	0 1 0 1 1 0	0.00077
Mm_7	0 1 0 1 2 0	0.00021
Msf_1	0 2 -2 0 -1 0	-0.00042
Msf_2	0 2 -2 0 0 0	-0.00583
Msf_3	0 2 -2 0 1 0	0.00038
Msf_4	0 2 -2 2 0 0	0.00004
Mf_1	0 2 0 -2 -1 0	0.00015
Mf_2	0 2 0 -2 0 0	-0.00288
Mf_3	0 2 0 -2 1 0	0.00019
Mf_4	0 2 0 0 0 0	-0.06663
Mf_5	0 2 0 0 1 0	-0.02762
Mf_6	0 2 0 0 2 0	-0.00258
Mf_7	0 2 0 0 3 0	0.00006

differing in frequency by one cycle in 18.61 years, having an amplitude of 0.41 of Mf_4. Rather than evaluate its amplitude directly from F.C.364, the closest in frequency, I have given it the same phase lag and relative amplitude as Mf_4, from the assumption that the oceanic response is similar over such a narrow range of frequencies. The phase lag of Mf_4 (referred to as g in harmonic analysis notation) is the difference in phase between F.C.363 of the observed sea levels, and that of the equilibrium tide.

Background noise introduces uncertainties into the amplitudes and phases, and biases the amplitude upwards, but not the phase. Fourier coefficients closest to the tidal frequencies have amplitudes E, due to contributions from the tidal lines H, and from the noise η, which are related by

$$E^2 = H^2 + \eta^2.$$

Values of η^2 can be estimated from neighbouring Fourier coefficients. Here, averages of η^2 over 17 to 19 coefficients (away from satellite tidal lines) were computed. Unbiased values H are given by

$$H = (E^2 - \eta^2)^{1/2}$$

The uncertainty in amplitude is given by Wunsch (1967) as $\pm\eta^{1/2}$ for one standard deviation. Wunsch approximated a formula for phase error given by Middleton (1948) and Wunsch's phase uncertainties were applied to produce the values listed in Table IV.

The total expected error is the sum of:

(1) error in admittance amplitude and phase used to correct the sea level spectra
(2) uncertainty due to residual background noise, noted above.

The former is given by Godin (1976) as:

$$e(\sigma) \sim \left[\frac{1-\gamma^2(\sigma)}{\gamma^2(\sigma)} \quad \frac{1}{(1-P)^{1/\eta}} \right]^{1/2}$$

where e is the error, γ is the coherence, η is the number of Fourier coefficients in the band average, and P is the probability that

$$|Z| - e \leq |Z'| \leq |Z| + e$$

$$\arg(Z-e) \leq \arg Z' \leq \arg(Z+e)$$

where Z' is the computed estimate of the true complex admittance. For a confidence of one standard deviation, P is 0.68.

At all four ports, the minimum value of γ surrounding the Mf and Mm frequencies is .86, giving

$$e = .07 \quad \text{for } |Z|$$

$$= 4^{\circ} \quad \text{for arg } Z$$

The estimated values of amplitude and phase for the fortnightly and monthly tides, together with the rms average of both uncertainties are listed in Table IV.

Mf and Mm have been treated as gravitationally forced tides, not shallow water tides, an assumption which is not strictly true for Mm. To examine the two effects, we can compare the relative amplitudes of the equilibrium potential of Mf and Msf (=11.4) with the observed relative amplitudes of these tides (=2.7 at Tofino, 3.9 at Prince Rupert). The relative enhancement of Msf at these two ports is likely due to shallow water effects in Msf. Table I shows the constituents which interact to generate shallow water tides. The expected strengths should be in proportion to the amplitude of the constituent interacting with M_2, and for Tofino these are

Msf	1.0 (S_2-M_2)	
Mm	0.73 (N_2-M_2)	
Mf	0.27 (K_2-M_2)	0.09 (K_1-O_1)
Msm	0.03 (λ_2-M_2)	

If we take the amplitude of Msf at Tofino and Prince Rupert as entirely due to shallow water effects, then the expected shallow water Mf tide is 0.27 of Msf, equal to 1.5 mm in amplitude, attributed to the K_2-M_2 interaction. It is a contribution one tenth as strong as the observed Mf, which can then be assigned to direct gravitational forcing.

Both the direct and shallow water Mf tides have the same frequency, so the assignment of the observed tide to either source matters only for modulation of the Mf tide, which is controlled by Mf_5 for direct gravitational forcing and by the modulation of M_2 and K_2 for shallow water forcing. Because the direct forcing dominates, Mf_5 will dominate the modulation.

By similar reasoning, one can see that the expected shallow water amplitude of Mm is 0.73 of Msf which is 4 mm, an amplitude slightly smaller than that observed at three of the four ports. Again, the origin of a tidal line affects only the modulation. The nodal modulations of Mm, N_2 and M_2 are ±13%, ±4%, ±4% respectively; the expected error due to modulation will then be no more than 14%. This error has not been included in the uncertainties in Table IV.

The results show that Tofino and Prince Rupert are similar in their behavior for Mf and Mm (and for Mfn as well, which is forced by the behavior of Mf). The Mf amplitude is significantly lower at Victoria, and the Mf phase is less at Vancouver than found at the remaining three stations. Whatever is reducing the Mf amplitude at Victoria also may be the cause of the low amplitudes found in the residual noise in Figure 1b, as sea level changes at long periods at Victoria are less than observed at the remaining three ports. The long period tides and the meteorologically forced sea level changes both

travel up Juan de Fuca Strait, and the configuration of the Strait may reduce the amplitude of the fluctuations on the northern side.

The phase difference of Mf between Vancouver and the other three ports is large, even if the effect of shallow water terms is included. The phase difference of sea level fluctuations between Tofino and Vancouver at frequencies near Mf, in other words, the meteorologically forced portion of the record, indicates a 4° shift, equivalent to four hours, far short of the observed Mf phase difference of 43° between Tofino and Vancouver. Any effect due to a local response of the Strait of Georgia or Vancouver Harbour which could affect the phase of the Mf tide, should also affect the sea levels at neighbouring frequencies, yet the two behave in a very different way, for which there is no explanation.

A comparison of the amplitudes and phases in Table IV with the vector averages found in Tables IIa to IId shows that most agree to within the error noted in Table IV, although the amplitudes of the Msf tides at Prince Rupert and Tofino given by harmonic analysis are far out of line.

These results show that although these four long period tides should not be included in a one year harmonic analysis of a west coast port, the vector average of Mf and Mm over at least fourteen years will give reasonable values of amplitude and phase for these two constituents.

Table IV. Amplitudes and Phases of Fortnightly and Monthly Tides

	Amplitude (mm)	Phase (degrees)
Mf		
Victoria	11.1 ± 1.6	151 ± 12
Vancouver	17.4 ± 1.9	124 ± 11
Tofino	17.2 ± 1.7	167 ± 9
Prince Rupert	19.5 ± 1.5	164 ± 7
Mfn		
Victoria	4.6 ± .66	151 ± 12
Vancouver	7.2 ± .79	124 ± 11
Tofino	7.1 ± .70	167 ± 9
Prince Rupert	8.1 ± .62	164 ± 7
Mm		
Victoria	6.6 ± 1.9	164 ± 21
Vancouver	3.0 ± 2.2	183 ± 45
Tofino	7.8 ± 1.9	162 ± 18
Prince Rupert	7.0 ± 1.6	146 ± 16
Msf		
Tofino	6.5 ± 1.9	213 ± 22
Prince Rupert	5.0 ± 1.5	309 ± 23
Msm		
None visible		

III. Annual and Semi-Annual Tides (Sa, Ssa)

In British Columbia, the seasonal air pressure, wind driven currents, seasonal heating and river flow determine the values of the Sa and Ssa tides. Because the weather dominates these tides, they are not as regular as gravitational tides, and an anomalous year can be expected to have sea levels differing from predicted values. Predictions of these tides can be improved if many years of observations are available. One easily obtained, long term average is the monthly mean of sea level at ports in Canadian waters, printed in "Monthly and Yearly Mean Water Levels, Volume 2, Tidal, 1975" published by the Marine Environmental Data Service. Monthly means at most ports date back further than the hourly heights analyzed for monthly and fortnightly tides. The twenty years from 1959 to 1978 comprised a data base to determine the average water level for each month and the standard deviation of the monthly means. Only years with all 12 months of data were included.

Graphs of annual sea level changes are found in Figures 15 and 16 plotted at ± one standard deviation. The sum of the Sa and Ssa tides fitted to these monthly means are plotted as the smooth line in Figures 15 and 16. To derive these constituents, several factors were allowed for:

1. Months of different lengths.

A cubic spline function was fitted to the monthly means, and heights at 12 equal time intervals were interpolated. The improvement in the function is marginal, but the programming is relatively easy. The cubic spline routine fits a smooth curve through each monthly mean, and is the standard method of interpolating readings with the aid of a computer. Equal time intervals between readings were necessary because a fast Fourier transform routine was employed to determine the Sa and Ssa amplitudes and phases.

2. Reduction of amplitude of Sa, Ssa due to averaging data.

Whenever a set of average values is used to determine tidal constituents, the amplitudes of the constituents are reduced. In this case, the averages are over a period of a month. The reduced amplitude can be determined from the following formula:

$$A_\eta(\sigma) = \frac{\sin \eta\pi\Delta t\sigma}{\eta \sin\pi \Delta t\sigma} \qquad \text{(Godin, 1972, p.62)}$$

The parameters have the following values:

	Sa	Ssa
η (hours)	730	730
Δt (hours)	1	1
σ (c/hour)	0.00011407712	0.00022815423
A_η	0.9886	0.9550

where η is the number of hours in the average,
Δt is the time between readings
σ is the frequency of the constituent
$A\eta$ is the reduced amplitude.

The actual value of η varies from 672 for most Februaries to 744 for months of 31 days. Because those months having 31 days tend to occur more frequently in summer and winter, the averaging is not uniform over the year, and there is a tendency for the amplitude given by the analysis program to depend upon the phase of the tide. This effect limits the accuracy of the amplitude analysis to about 0.2%, but with the erratic behavior of the Sa and Ssa tides, this limit is quite tolerable.

3. Frequencies.

In the program for harmonic analysis of tides (Foreman, 1977), Sa and Ssa have the Doodson numbers and frequencies:

Sa	00100-1	(.0001140741 c/hour)
Ssa	00200-0	(.0002281591 c/hour)

These are the Doodson numbers associated with the gravitational potential. Note that Ssa is not twice the frequency of Sa. The gravitational Sa appears in the development of the terms involving the 4th power of the solar parallax, and so depends upon the speed of the solar perigee, denoted by the last Doodson number. This speed is less than 2^{o}/century.

If monthly means are used to derive Sa and Ssa constituents, then we are implicitly assuming that Sa and Ssa have Doodson numbers and frequencies of:

Sa	001000	(.0001140795 c/hour)
Ssa	002000	(.0002281591 c/hour)

Where both depend only on the length of the tropical year and the frequency of Sa is one half that of Ssa. This scheme is proposed by Shureman (1958), and is used by the National Ocean Survey in the United States for tidal analysis.

Because the two Sa frequencies are similar, the predicted value, using the gravitational Sa will diverge very slowly from the observed, and could be neglected for any one century. However, the phases are different by 77.5^{o}, and one should be careful that the proper phase is used. Because Foreman's programs are the prediction schemes in Canada, I have followed his convention scheme for Sa and Ssa, and computed phases from the monthly means relative to the gravitational tide. Note that only Sa has this discrepancy, and only with the phase is there likely to be any confusion.

4. Leap Years.

I have assumed the year to be 365.25 days long, so that the frequencies of Sa and Ssa are:

Sa	0.00011407712 cycles/hour
Ssa	0.00022815423 cycles/hour

This is not strictly true over many hundreds of years, but is true for the interval from 1901 to 2099, the period for which these analyses are intended.

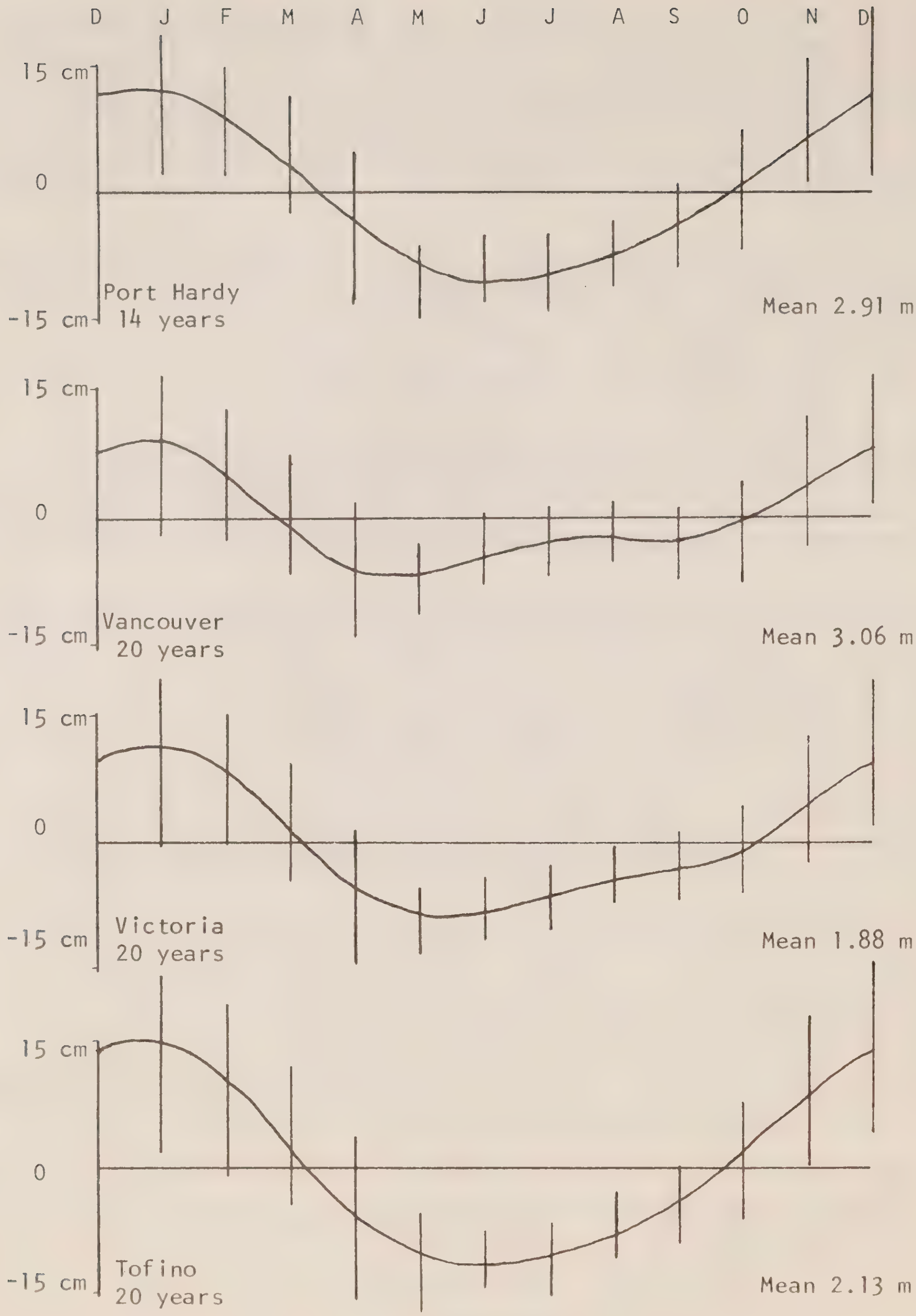


Figure 15. Vertical lines are monthly means ± 1 standard deviation. Curved line is predicted value using Sa and Ssa constituents.

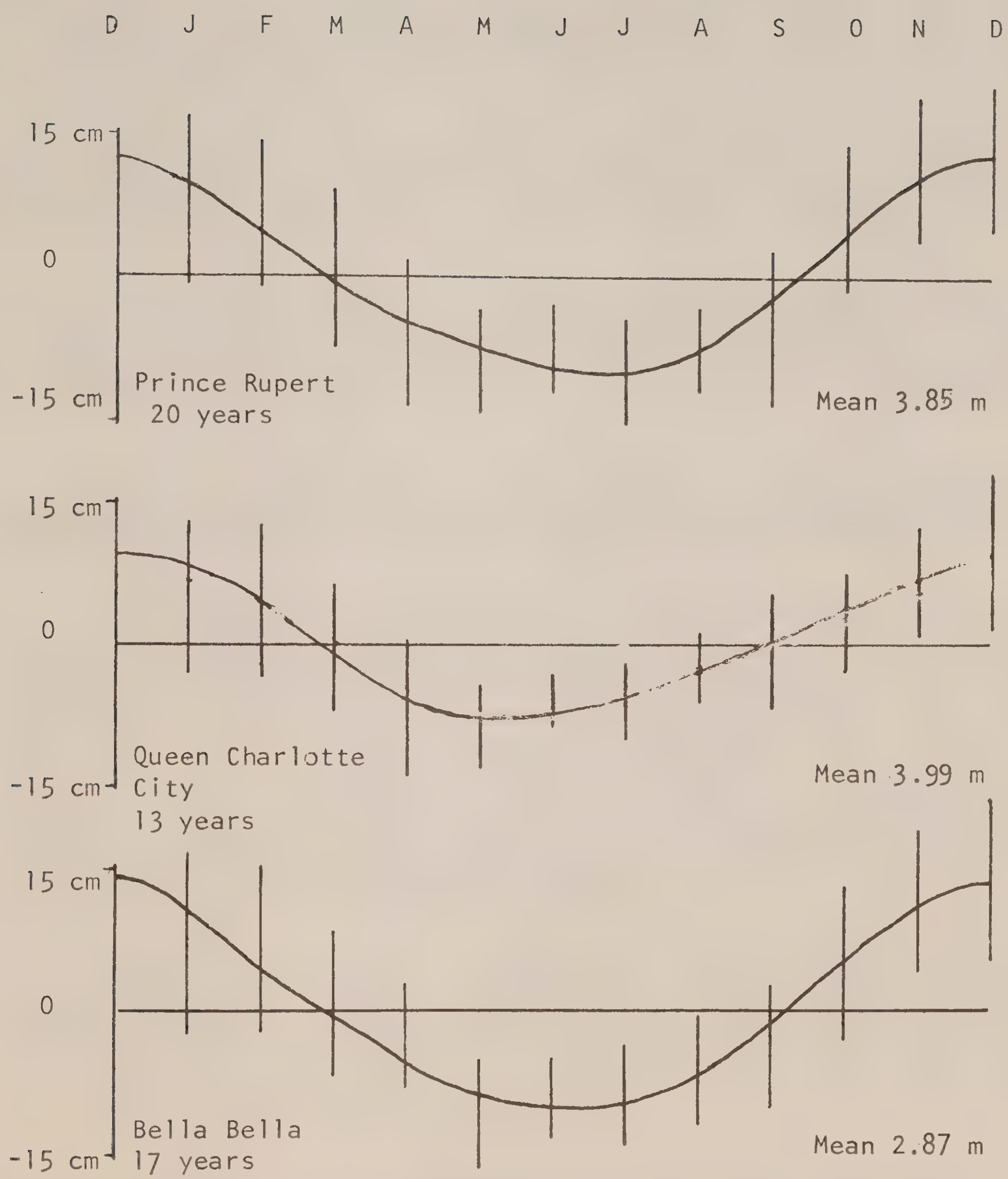


Figure 16. Vertical lines are monthly means ± 1 standard deviation. Curved line is predicted value using Sa and Ssa constituents.

Table V lists the amplitude and phase of Sa and Ssa at the British Columbia ports found in Figure 15 and 16.

Several features emerge. The seasonal change in standard deviation reflects the more variable weather conditions found in winter. A typical range found for Sa, about 20 cm surpasses the range in seasonal air pressure changes in British Columbia, as can also be seen in figures 7 to 10. Geostrophic currents, flowing along the British Columbia coastline, driven by seasonal winds, generate much of the Sa tide. Largest seasonal changes are at Tofino, where currents will most strongly influence sea levels. Prince Rupert, located further north where currents are not as seasonal, has a lower Sa tide, although winter to summer air pressure changes are larger there.

Vancouver and Victoria show a secondary rise in sea level in summer, stronger at Vancouver, due to Fraser River freshet. Prince Rupert and Queen Charlotte City exhibit a slight rise in sea level in June, likely due to the runoff of the Skeena River.

All predicted values are within one standard deviation of the average monthly means, but to generate improved predictions, which would show the secondary uses in sea level noted above, the monthly means themselves could be employed.

Table V. Amplitudes and Phases of Solar Annual (Sa) and Solar Semi-annual Tides at Seven British Columbia Ports.

	Sa		Ssa	
	Amplitude (cm)	Phase (deg)	Amplitude (cm)	Phase (deg)
Tofino	12.8	356	2.3	236
Victoria	9.1	354	2.7	240
Vancouver	6.5	347	3.6	224
Port Hardy	11.3	358	1.5	233
Bella Bella	11.5	345	1.2	175
Queen Charlotte City	8.3	338	1.6	223
Prince Rupert	11.1	348	1.9	144

IV. Meteorological Effects

In Section II, the spectral comparisons of sea levels and air pressures showed a tendency for an inverted barometer overshoot at Tofino, Victoria, Vancouver and Prince Rupert. To show this tendency throughout British Columbia waters, low passed sea levels (solid line) and air pressures (dashed line) are plotted in Figures 17a to 17e. The sea level record was prepared by applying a Cosine-Lanczos 120 hour filter (50% power at 40 hours, 90% power passed at 48 hours) to the residual sea levels, and truncating the time series to twice daily readings. Only gravitational tides were removed from the record. The annual (Sa) and semi-annual (Ssa) tides remained. The air pressure record was similarly filtered and truncated. Vancouver Airport air pressures serve both Vancouver and Victoria sea levels; Sandspit air pressures are compared with Queen Charlotte City; Cape St. James air pressures are compared with Bella Bella; other sea level time series are plotted with air pressures measured at weather stations within a few kilometres. All positions are indicated in Figure 1.

The time series run from 3 January 1976 to 28 July 1977, an interval determined by the availability of data at these stations. Most tide gauges run continuously and trouble free, but the Langara gauge due to its exposed and remote location operates less reliably, and the interval shown coincides with its best record.

Each chart covers four months of data, over the periods Jan.-April, May-Aug., Sept.-Dec. The long period mean sea levels, given in Section III have been subtracted from each record. The units are centimetres for sea level, and millibars for air pressures.

In Section II it was noted that sea levels and air pressures were out of phase by roughly 180° (exact values varied from 170° to 200° depending upon port and period), and sea level fluctuations were larger. Both these features stand out in Figures 17a to 17e. It is also apparent that the sea levels and air pressures are coherent between adjacent ports, with a fair degree of coherence over all ports. Closest agreement is found among the three southern stations: Tofino, Vancouver and Victoria. Queen Charlotte City and Bella Bella sea levels are alike as are Prince Rupert and Langara, but between these two sets, for example between Queen Charlotte City and Prince Rupert, there are often abrupt changes.

Fluctuations in both time series are largest in winter, smallest in summer, due to winter storms. The biggest fluctuations, of amplitudes greater than 30 cm, are found at Langara and Prince Rupert in winter. As a rule, winter sea levels are characterized by sharp highs, and summer sea levels by alternating highs and lows superimposed upon the depressed sea levels generally found at that time of year.

The extreme values in sea levels are reduced by the Cosine-Lanczos filter, which attenuates signals of periods less than two days and decimates those of one day period or less. The best example of this averaging is by comparison with the Prince Rupert residual unfiltered sea level record found in Figure 6. Residual tides are smallest at Prince Rupert but meteorological effects are large. At Day 39 both records show a large sharp sea level increase at Prince Rupert, but this increase is

70 cm on the unfiltered record and only 45 cm on the filtered one. The largest filtered residual tide found in Figure 17 is 55 cm at Tofino at the end of February 1977. The corresponding actual residual tide would be about a metre in amplitude, as this peak is quite sharp. For the ports shown in Figure 17, the largest deviation of observed from predicted tides is about a metre.

It was noted earlier that the inverted barometer overshoot could be attributed to alongshore winds on the west coast. To examine this effect an anemometer and several current meters were moored off Estevan Point on the west coast of Vancouver Island during the summer of 1979 as part of the Coastal Ocean Dynamics Experiment. The moorings, denoted as E01 and E02, were moored 15 and 30 km from shore respectively, in water one to two hundred metres deep. Both moorings were on the continental shelf. The anemometer was placed near mooring E02. To provide nearby sea level data a subsurface pressure recorder was deployed in Nootka Sound a few kilometres to the north of Estevan Point. Because this gauge measures the sum of the water and air pressure above it, the record which it supplies is designated the adjusted sea level. At any of the ports shown in Figures 17a to 17e, the adjusted sea level could be computed by adding the sea levels to the air pressures. Where there is an inverted barometer overshoot, the adjusted sea levels have a shape similar to the sea levels, but of smaller amplitude.

The adjusted sea level and alongshore components of the wind and current were filtered with the Cosine-Lanczos filter and plotted in Figure 18. It can be seen that many of the fluctuations in the alongshore wind are found in both the adjusted sea levels and alongshore currents at the E01 mooring. Even farther from shore at mooring E02 where the fluctuations decrease in amplitude, many of the same features appear. The alongshore current at the surface is set up by the alongshore wind, and the Coriolis force causes a northwestward current to raise sea levels at shore, and southeastward currents to lower sea levels. The changes in sea levels are most pronounced at shore, causing the sea surface to slope up toward shore for a northward current, with a resulting pressure force in the water column which pushes the water away from shore. Below the surface Ekman layer, which off Vancouver Island in summer is about 20 m deep, the wind has little direct influence on the currents and there is, for northwestward winds and surface currents, an offshore flow driven by the pressure force. The Coriolis force turns this flow to the right, or northwest for an offshore flow, with the result that the entire water column is now flowing to the northwest. It is this secondary flow pattern which causes the wind driven current fluctuations to exist at all depths in the continental shelf waters, and drives the adjusted sea level changes noted in Figure 18. The current and sea level fluctuations found here are similar to those observed by Smith (1974) along the Oregon Coast. It is expected that the eighteen months of sea level, air pressure and ocean current data gathered during CODE in 1979 and 1980 will provide more insight into the nature of sea level changes along the coast.

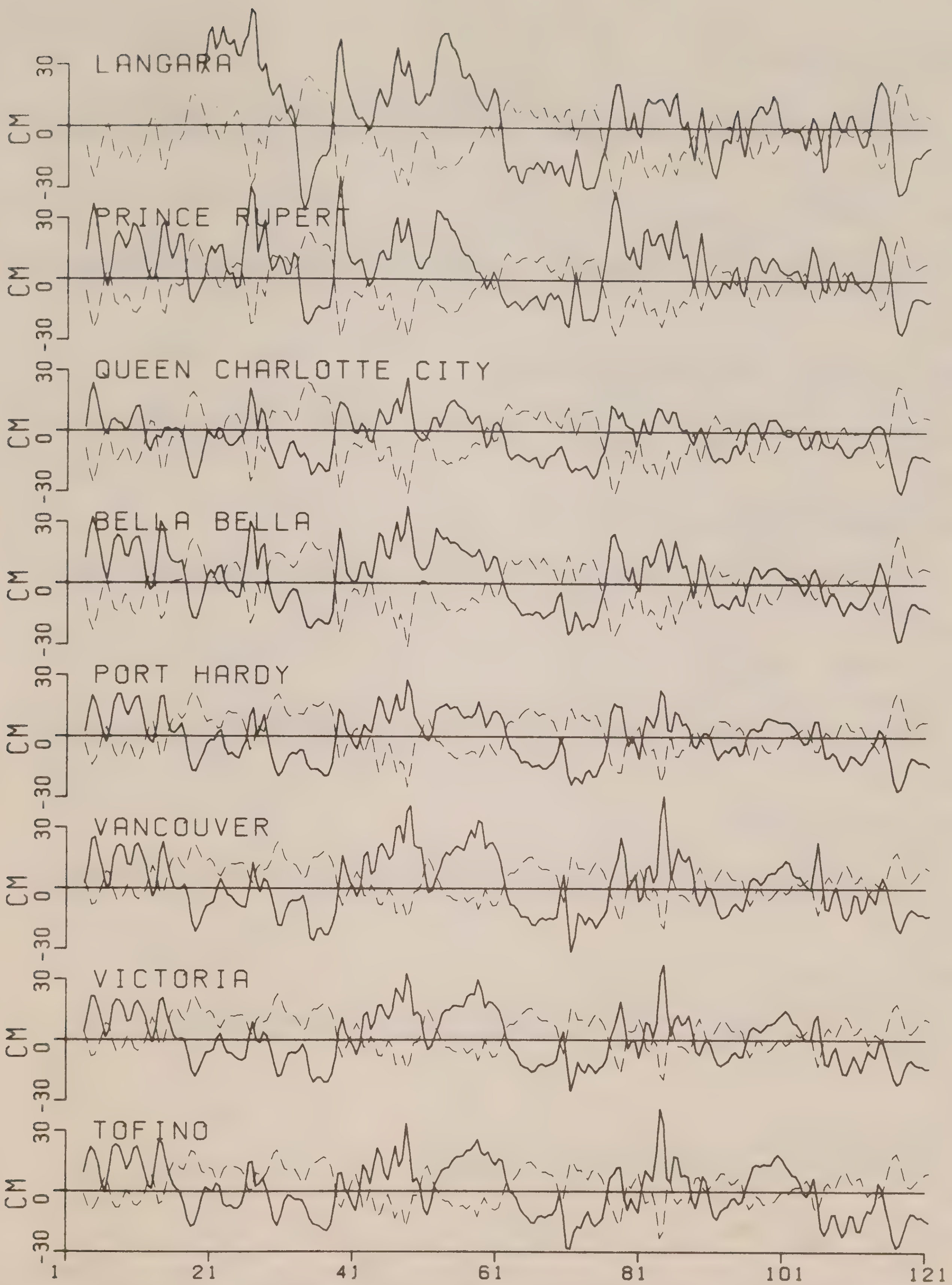


Figure 17a. Filtered residual sea levels (solid line) and filtered air pressures (dashed lines) at ports in British Columbia, January to April, 1976.

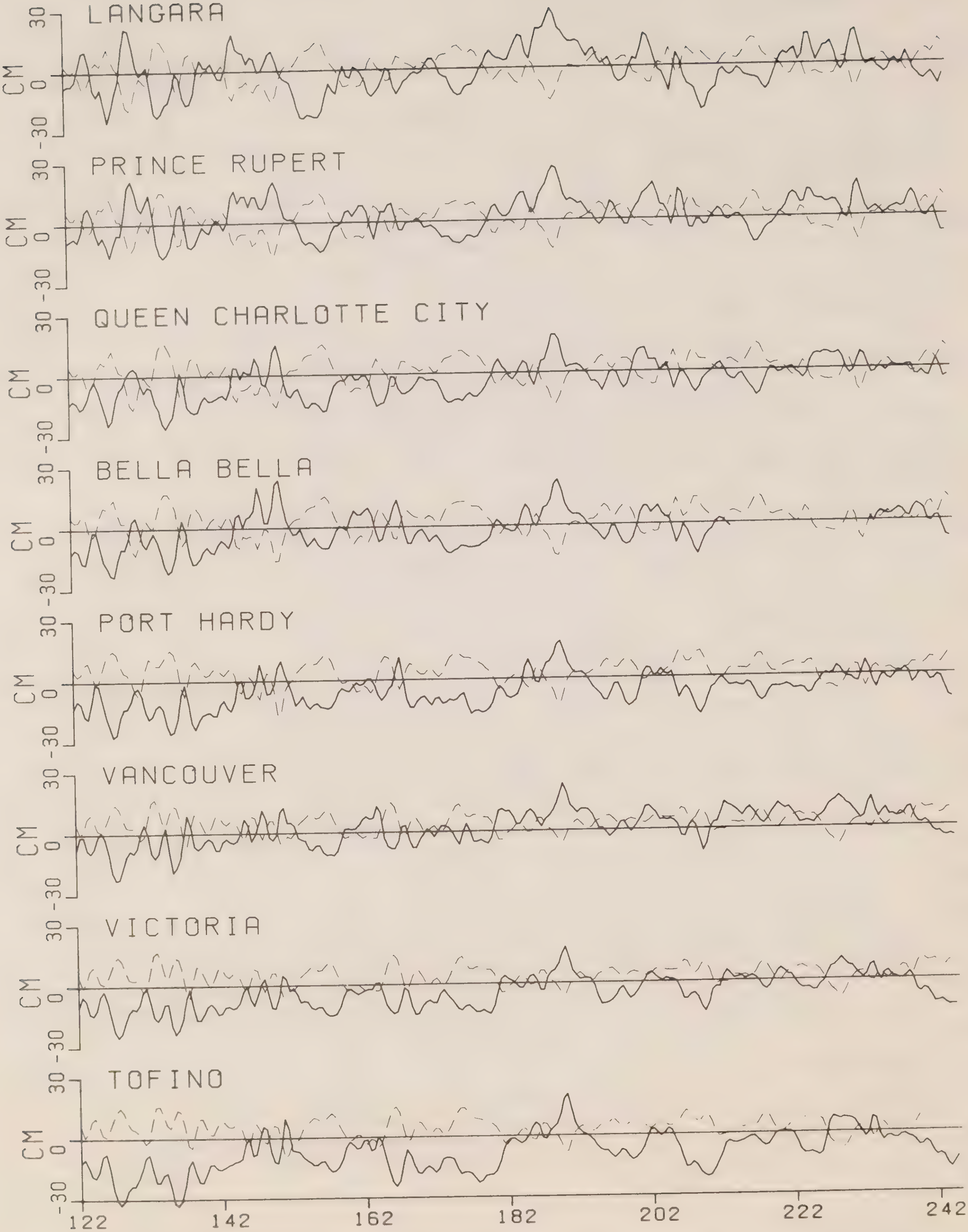


Figure 17b. Filtered residual sea levels (solid line) and filtered air pressures (dashed line) at ports in British Columbia, May to August, 1976.

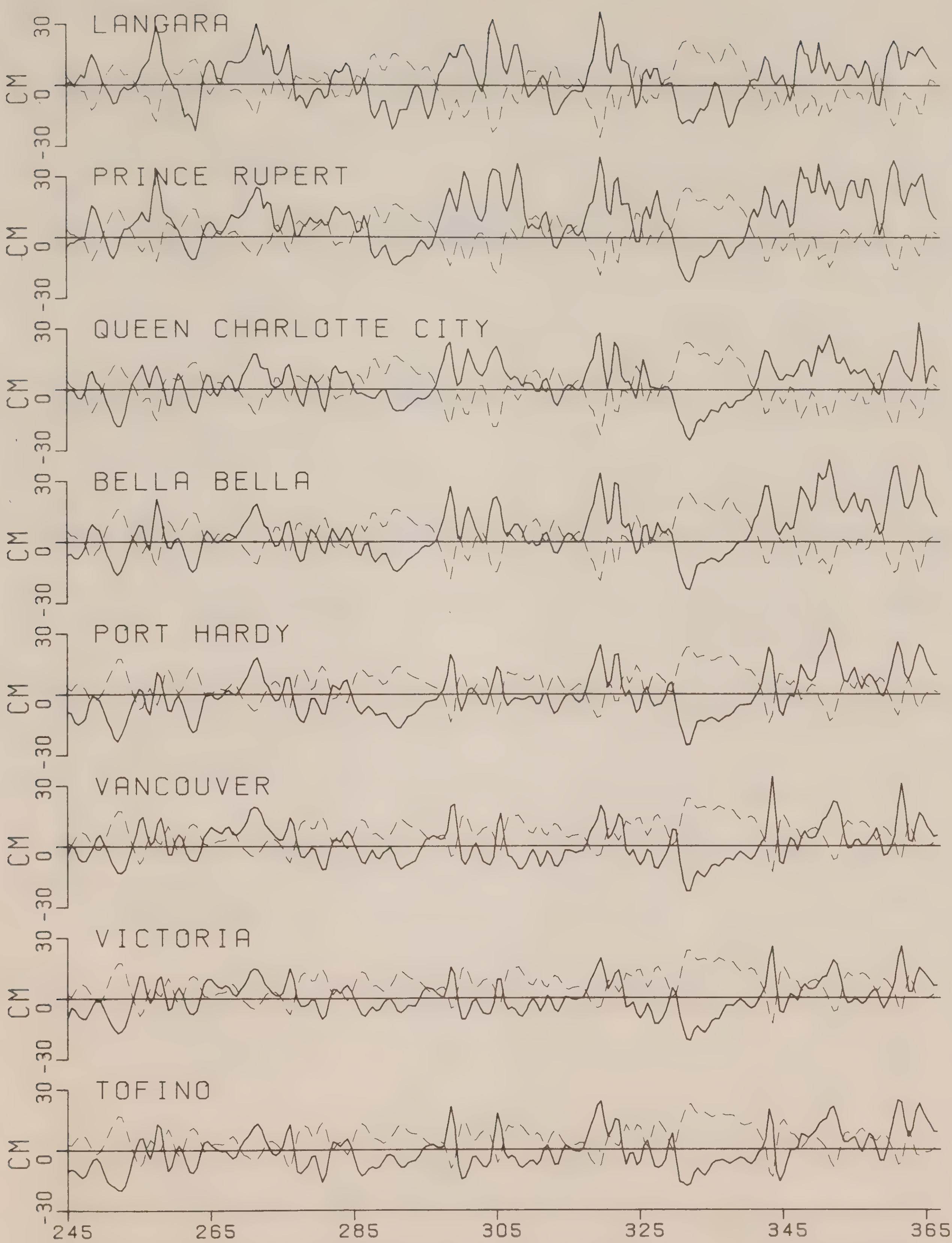


Figure 17c. Filtered residual sea levels (solid line) and filtered air pressures (dashed line) at ports in British Columbia, September to December, 1976.

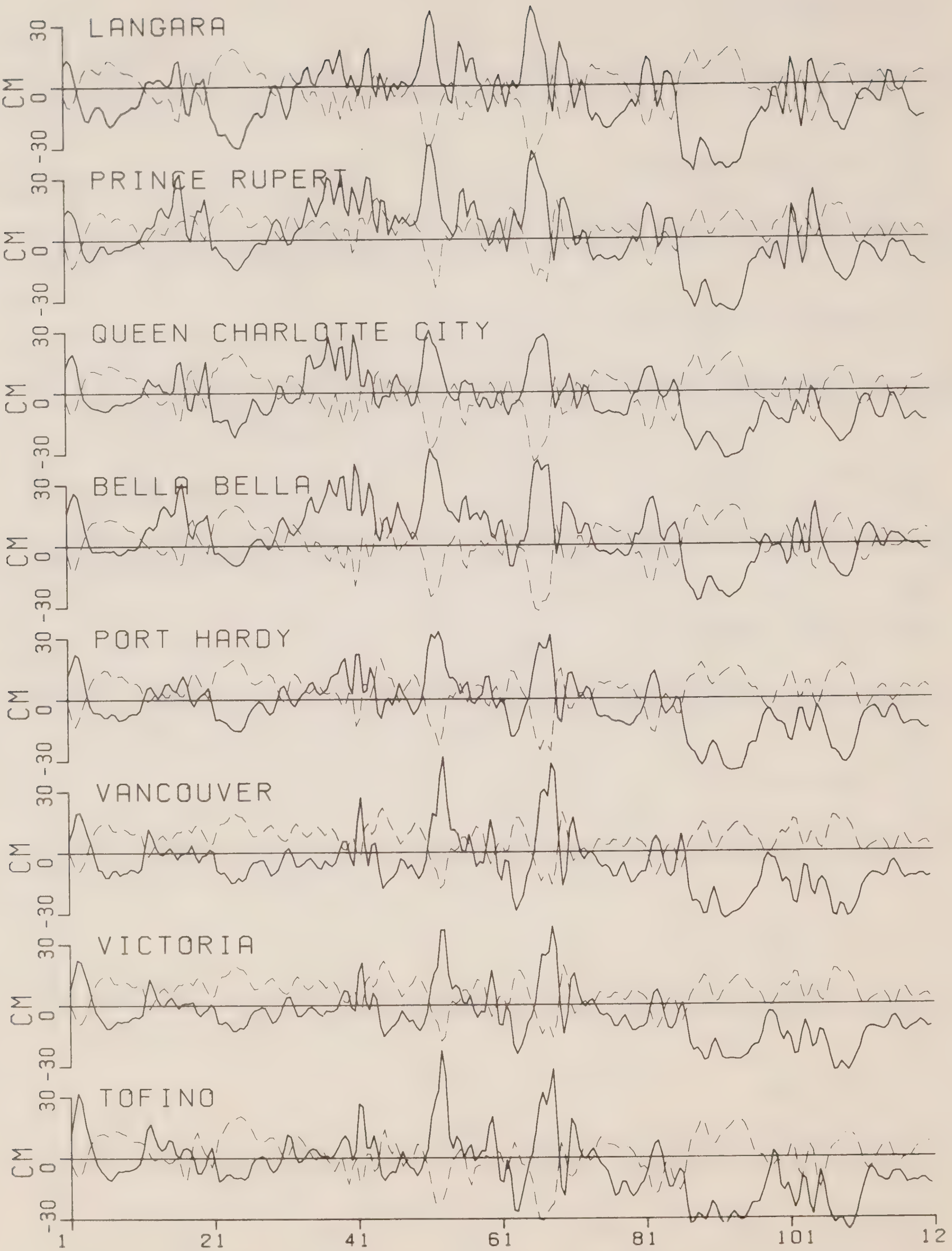


Figure 17d. Filtered residual sea levels (solid line) and filtered air pressures (dashed line) at ports in British Columbia, January to April, 1977.

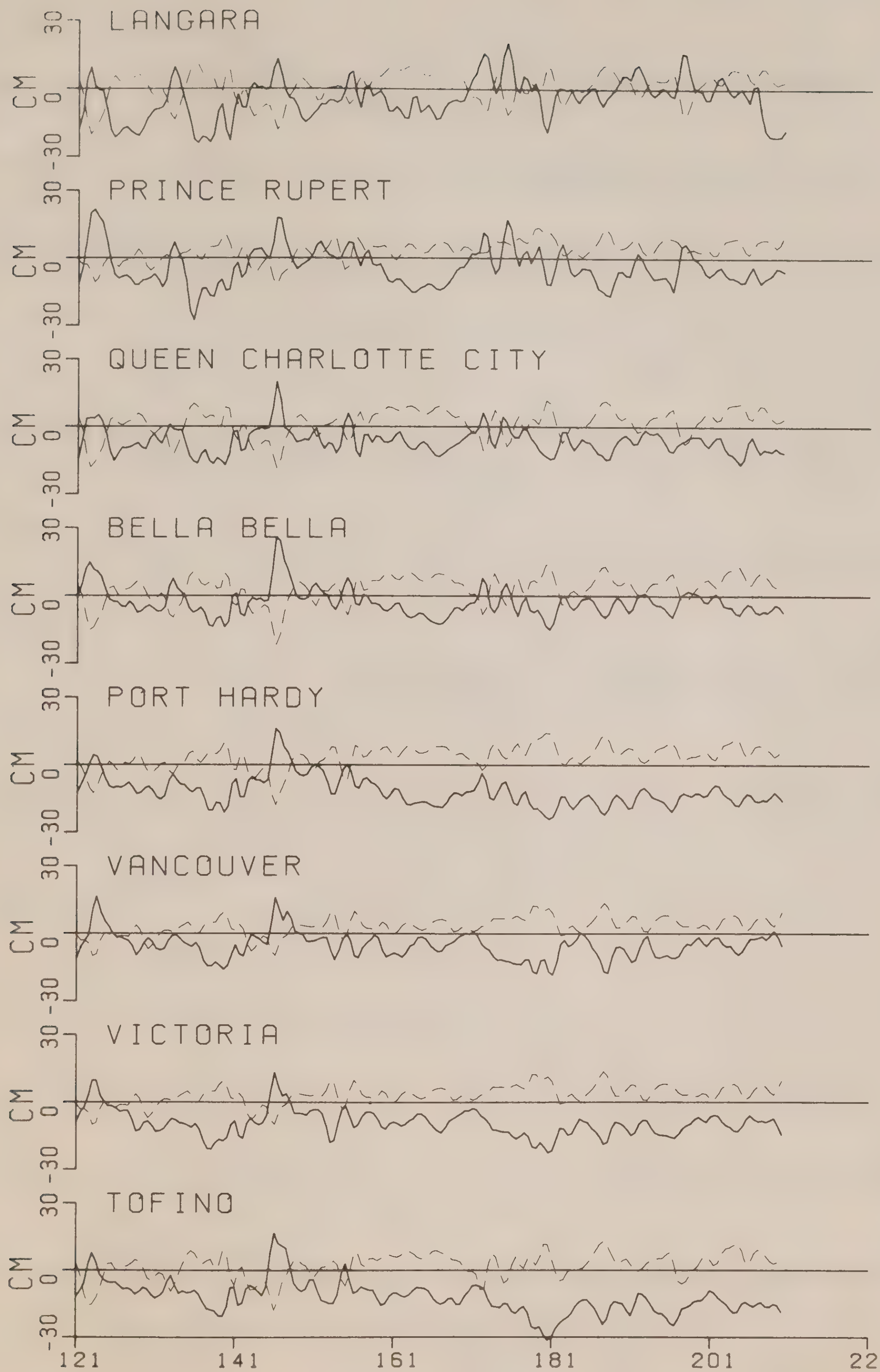


Figure 17e. Filtered residual sea levels (solid line) and filtered air pressures (dashed line) at ports in British Columbia, May to August, 1977.

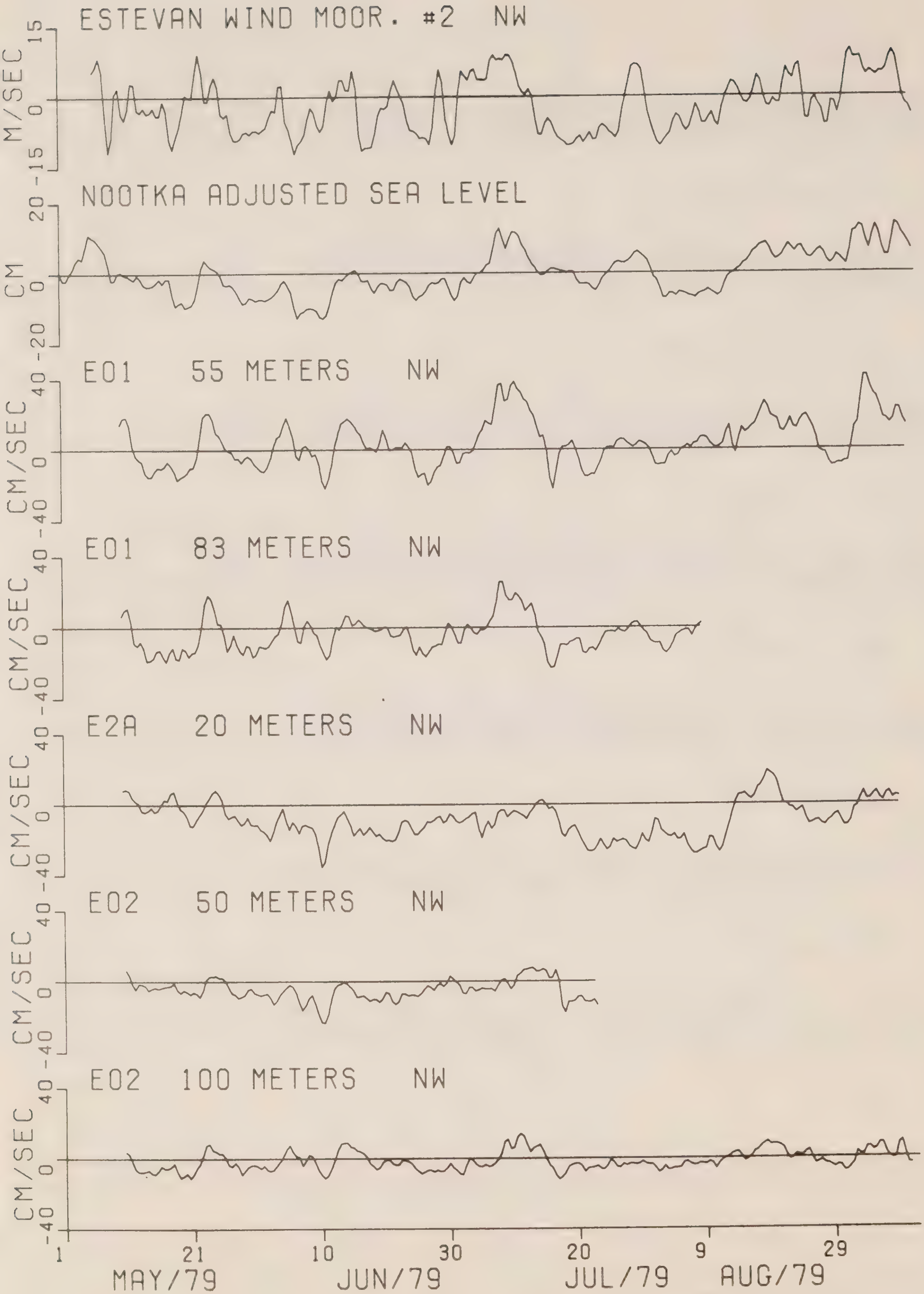


Figure 18. Adjusted sea level and alongshore winds and currents near Estevan Point, May to September, 1979.

REFERENCES

Adams, J.F. and V.T. Buchwald, 1969. The generation of continental shelf waves. J. Fluid Mech. 35: 815-826.

Brown, W., W. Munk, F. Snodgrass, H. Mofjeld, B. Zetler, 1975. MODE bottom experiment. J. of Phys. Oceanogr. 5(1): 75-85.

Cartwright, D.E. and A.C. Edden, 1973. Corrected tables of tidal harmonics. Geophys. J.R. Astr. Soc. 33: 253-264.

Crawford, W.R., W.J. Rapatz and W.S. Huggett, 1980. Pressure and temperature measurements on seamounts in the North Pacific, submitted to Marine Geodesy.

Crepon, M., 1976. Sea level, bottom pressure and geostrophic adjustment. Memoires Soc. Roy. des Sciences de Liège. 6th series, Vol. X: 43-60.

Foreman, M.G.G., 1977. Manual for Tidal Heights Analysis and Prediction. Institute of Ocean Sciences, Patricia Bay, Pacific Marine Science Report 77-10. 97 pp.

Gill, A.E. and E.H. Schumann, 1974. The generation of long shelf waves by the wind. J. Phys. Oceanogr. 4(1): 83-90.

Godin, G., 1972. The Analysis of Tides. University of Toronto Press, 264 pp.

Godin, G., 1976. The use of the admittance function for the reduction and interpretation of tidal records, Marine Sciences Directorate, MRS 41, Ottawa. 46 pp.

Huyer, A., R.L. Smith and E.J. Sobey, 1978. Seasonal differences in low-frequency current fluctuations over the Oregon continental shelf. J. Geophys. Res. 83: 5077-5089.

Lisitzin, E., 1973. Sea Level Changes. Elsevier Oceanography Series, Elsevier Scientific Publishing Company, New York. 286 pp.

Middleton, D., 1948. Some general results in the theory of noise through non-linear devices. Quarterly of Applied Math. 5: 445-498.

Osmer, S.R. and A. Huyer, 1978. Variations in the alongshore correlation of sea level along the west coast of North America. J. Geophys. Res. 83(C4): 1921-1927.

Reid, J.L. and A.W. Mantyla, 1976. The effect of the geostrophic flow upon coastal sea elevations in the northern North Pacific Ocean. J. Geophys. Res. 81(18): 3100-3110.

Shureman, 1940. Manual of Harmonic Analysis and Prediction of Tides. U.S. Dept. of Commerce, Coast and Geodetic Survey, Special Publication No. 98, 317 pp.

Smith, R.L., 1974. A description of current, wind and sea level variations during coastal upwelling off the Oregon Coast. July-August 1972. J. Geophys. Res. 79(6): 825-830.

Wunsch, C., 1967. The long-period tides. Rev. of Geophysics. 5(4): 447-475.